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Results of the Groundwater Geochemistry Study on Hornby Island, British Columbia

Final Report

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EXECUTIVE SUMMARY

Because groundwater supplies the majority of potable water in many coastal communities and islands in British Columbia, more attention is being paid to its quality and quantity, and to the processes that potentially threaten this valuable resource. This study benchmarks the current groundwater chemistry on Hornby Island, characterizes the general evolution of groundwater on the island, and provides data for future studies involving the chemical evolution of groundwater on the Gulf Islands.

Water samples were collected from wells volunteered by local residents under the auspices of a joint pilot project between the B.C. Ministry of Environment, Lands and Parks, the Islands Trust and Simon Fraser University. Water samples were analyzed for dissolved ionic species (i.e., metals and common anions) and were interpreted in the context of the local geology in order to provide information on the chemical character of groundwater (including the spatial distribution of dissolved metals and anions), the evolution of groundwater within different flow regions, and the location of recharge and discharge areas.

Groundwater on Hornby Island is recharged locally, typically at high elevation in areas corresponding to Mount Geoffrey and the Crown Land. However, the relatively immature chemical composition of many well waters (calcium-bicarbonate type water) situated at lower elevations suggests that recharge occurs over a significant portion of the island. Many groundwaters have undergone extensive cation exchange, a process whereby sodium replaces calcium during and following the dissolution of calcite. It is suggested that groundwater flow through fractured mudstone units may be the cause for the high occurrence of cation exchange. Mature groundwaters, characterized by higher concentrations of chloride, result from mixing between the Na-rich groundwater and seawater. Several wells in the Whaling Station Bay area show significant salinization, and suggest that saltwater intrusion may be prevalent in that area.

ACKNOWLEDGMENTS

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To the residents of Hornby Island, thank you. Without your valued cooperation the collection of such a large number of samples would have been difficult. It is your participation in this project that allowed us to collect and analyze the data obtained from your wells. This research could not have been done without your support.

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1.0 INTRODUCTION

1.1 Background

Groundwater plays a critical role in supplying potable water to the residents of the Gulf Islands. For the most part, groundwater supplies on these islands are derived wells completed in fractured sedimentary rock aquifers, although surficial sand and gravel deposits accessed by shallow wells provide potable water in some local areas. In 1993, Hornby Island was chosen by the Islands Trust and Ministry of Environment, Lands and Parks (MELP) as the site of the first of two groundwater pilot projects under the "Freshwater Initiative" initiated in an attempt to evaluate the adoption of provincial groundwater regulations. It is under the auspices of this pilot project that the current sampling program was conducted.

Hornby Island, one of the two northern-most Canadian Gulf Islands, is located approximately 70 km north of Nanaimo and approximately 2 km east of neighbouring Denman Island (Figure 1). The island is roughly 31 km^2 in area and supports a permanent population of approximately 1200 (The Hornby Island Groundwater Pilot Project, 1994) (Figure 2). Population increases seasonally; in particular during the summer as off island residents and tourists arrive. In comparison, Saltspring, Mayne and Saturna Islands have full-time populations of 9240, 997 and 315, respectively (Canada Census, 1996).

Residential lots are most heavily concentrated along the eastern, northern and western shorelines, with fewer lots developed on the upland Mount Geoffrey area. In 1978, several large waterfront farms were subdivided into high-density residential parcels with areas of less than 0.2 hectares. In an attempt to prevent groundwater and sewage disposal problems associated with small high density residential lots, the Provincial Government applied an interim minimum lot size of 10 acres to all future development on Hornby Island. The current minimum small residential lot size has been set at 3.5 ha (8.6 acres) as per the 1993 draft of the

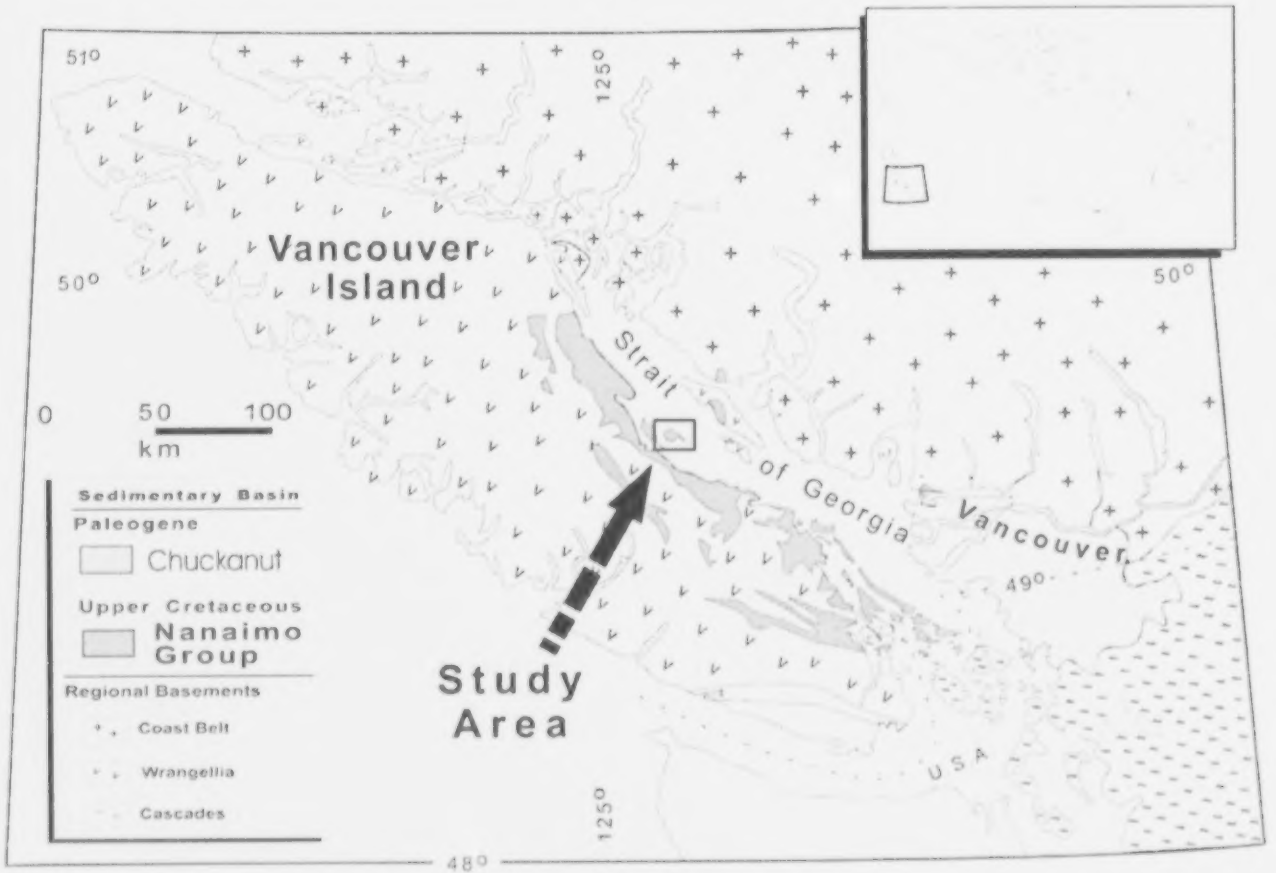

Figure 1. Regional Setting of the Nanaimo Group and Hornby Island (Geology from Mustard, 1994)

Figure 2. Hornby Island location Map (after Katnick, 2001)

Hornby Island Land Use By-law. Residential lot development and land use planning is currently the mandate of the Islands Trust, which is the regional district government agency.

1.1.1 Understanding Groundwater Resources of Islands

The development of islands, which rely almost exclusively on groundwater as a supply of potable water, necessitates an evaluation of the long-term sustainability of groundwater resources. Sustainability of the resource is dependent upon a number of factors including the amount of recharge that is received annually by the aquifers, the geological and topographic complexity of the island, and the water use patterns. While the annual seasonal precipitation for Hornby Island averages 1370 mm (The Hornby Island Groundwater Pilot Project, 1994), the summer months are generally much drier. Therefore, consideration must be given to the sustainability of the resource, particularly over the summer months.

Typically, only a portion of the total amount of rainfall infiltrates the subsurface. Estimates of recharge derived for many of the Gulf Islands are approximately 20%, although spatial variability can be expected on the basis of topography and geology. Nevertheless, the relatively low values of recharge present a potential problem, particularly to those areas that receive relatively little recharge or where significant volumes of groundwater are extracted. Most natural hydrogeological systems maintain a balance between the amount of recharge, the amount of discharge and the amount of water retained in storage. If no groundwater is extracted, then the system is generally in dynamic equilibrium (climate factors aside) and water input equals water output. On an island, water input (recharge) is normally limited to the island surface itself (i.e., there are no external sources), and output is to the ocean, surface streams, rivers and lakes.

When groundwater is extracted from wells, the result is a shift in the natural balance. If the same amount of recharge is applied, then it can be expected that

there will be either a reduction in the amount of groundwater held in storage, a reduction in the baseflow to streams, or a reduction in the amount of groundwater that discharges to the ocean. Reductions in the amount of storage result in a lowering of the water table (as evidenced by wells that run dry, and pumps that must be lowered to maintain yield, and the drying up of wetlands), reductions to baseflow can potentially lead to dry streams, and reductions in the amount of ocean discharge can result in saltwater intrusion (see Section 1.1.4). Many of these impacts are manifest not only in the quantity of groundwater that is accessible for consumption, but also in the quality of groundwater that is extracted.

Over the past several years drinking water quality and quantity have suffered in response to ever increasing demands placed on Hornby Island's groundwater resources (The Hornby Island Groundwater Pilot Project, 1994). Complaints of salty tasting and sulphurous drinking water are becoming more common, especially during summer months when the seasonal population of the island grows and when recharge of the groundwater system is at a minimum.

1.1.2 Water Chemistry Data

Water chemistry data obtained by sampling groundwater wells, surface waters and springs can provide important information on groundwater resources. Therefore, a water sampling program is normally a component of most detailed hydrogeological investigations. In addition to providing baseline data that can be used for future studies related to water quality deterioration and resource sustainability, these data may be used to:

1. **Define general trends that describe the natural evolution of water**. In an island aquifer system, groundwater generally evolves from a calcium (Ca) – bicarbonate (HCO_3) composition (recharge areas) to a sodium (Na) – chloride (Cl) composition similar to seawater (discharge areas).

2. **Identify the recharge and discharge areas based on two main criteria:**
    - *The amount of total dissolved solids (TDS).* As groundwater moves through the ground it dissolves minerals. Generally, the longer the residence time in the subsurface the higher the concentration of total dissolved solids.
    - *The relative concentrations of chemical species.* Chemical processes in aquifers result in certain relative concentrations of dissolved species that can be used to identify the origin of dissolved species, and thus, provide information on the travel path of groundwater.

3. **Identify areas that have unusually high concentrations of dissolved metals or anions that may exceed drinking water guidelines**. This information may be useful for identifying areas where development should be curtailed or where alternative water sources may be required.

4. **Study processes that may be active in the system (e.g., saltwater intrusion)**. In coastal aquifers, contamination by saltwater intrusion is a potential threat. Identifying areas that may be prone to saltwater intrusion may be used to develop guidelines for limited development in these areas.

1.1.3 Previous Studies on the Groundwater Chemistry of Gulf Islands

Comprehensive studies of the hydrochemical characteristics of aquifers on the Gulf Islands are limited. Furthermore, of the studies conducted, most have been focused on limited areas of the more populated southern Islands (e.g., Mayne and Saltspring). In the 1970s, a chemical study groundwaters was conducted on Mayne Island to determine the origin of saline groundwater (Dakin et al, 1983). That study included sampling of a small number of wells and leaching experiments on rock chip samples collected during drilling.

Dakin et al. (1983) proposed four possible origins of saline groundwater based on chemical data for Mayne Island:

1. Soluble salts (such as halite) that are present within the sedimentary strata that now exist in zones of active groundwater flow in the bedrock.
2. Marine water trapped in fractured bedrock strata that are currently raised above present sea.
3. Ocean water intruded into bedrock aquifers under present hydrologic conditions.
4. Formational brines that flow upward from deep (>1000 m) sedimentary zones.

Dakin et al. (1983) concluded that saline groundwater on Mayne Island is of a Na-Cl type, and that salinity is not due to the mixing of deep formational brines. Rather the presence of Na and Cl was thought to be due to the slow diffusion of these ions through the mudstones from which they appear to be derived. Active saline intrusion was viewed as being only a minor contributor to the overall Na and Cl concentrations.

In 1997/98, a comprehensive hydrochemical study was conducted on Saturna Island (Allen and Suchy, 2001). This study described the chemical evolution of groundwater on the island, and identified two major contributors to salinity. These included: 1) salinity due to mixing of fresh groundwater with older saline groundwater resident in the rocks possibly since the Pleistocene, and 2) salinity due to saltwater intrusion. Allen et al. (2001; in press) examined borehole geophysical logs in combination with hydrochemical data to study saltwater intrusion. By identifying localized zones of decreased electrical resistance and relating these occurrences to elevated total dissolved solids (TDS), pathways for contamination by saline groundwater were found to be associated with fractures

in the bedrock. The studies by Allen and Suchy (2001), Allen et al. (2001; in press), and Dakin et al. (1983) constitute a large portion of the recent hydrochemical work conducted in an attempt to characterize the nature of groundwater evolution on the Gulf Islands.

1.1.4 Salinization of Coastal Aquifers

Coastal aquifers are potentially at increased risk of degradation from contamination due to the process of saltwater intrusion. Saltwater intrusion is a process that results in a shift of the interface that exists in a coastal aquifer between "fresh" groundwater aquifers and the ocean. Numerous examples of coastal aquifer salinization are known around the world. For example, parts of Florida and the eastern coast of North America are currently experiencing salinization problems. More locally, portions of the American San Juan Islands are contaminated by saltwater.

The active intrusion of seawater into unconfined, or shallow confined coastal freshwater aquifers occurs as a result of an imbalance between the driving force (hydraulic head) that causes groundwater to flow from areas of high hydraulic head to areas of lower hydraulic head (i.e., along the hydraulic gradient). Generally, hydraulic head is high in inland areas and lower along the coast, and as a result, groundwater usually flows from areas of high elevation to areas of lower elevation (Figure 3a). However, depending on the topography of a given area, the amount of water that recharges an aquifer, and the flow patterns within the aquifer, the natural hydraulic head gradient may not be sufficient to keep seawater from flowing landward.

The saltwater intrusion mechanism can best be thought of as a dynamic equilibrium between the hydraulic gradient driving groundwater seaward and the hydraulic gradient exerted by the ocean in a landward direction. For the most

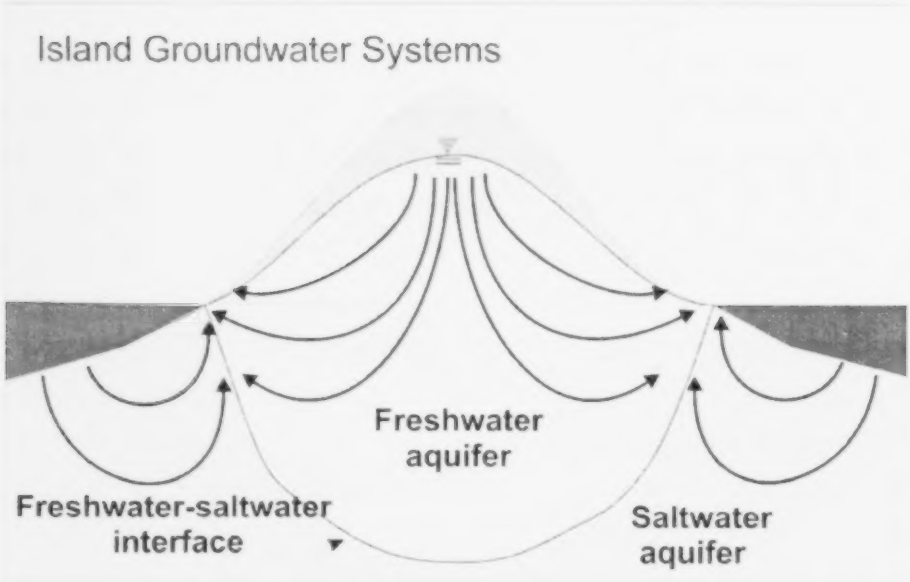

Figure 3a: Representation of groundwater flow in an island aquifer system

part, the hydraulic gradient within the freshwater aquifer exceeds the gradient exerted by the ocean, and freshwater is able to flow out into the ocean. In shallow confined aquifers, freshwater can travel significant distances out into the ocean before issuing forth as a submarine freshwater spring. In contrast, when the hydraulic head on the landward side of the freshwater-saltwater interface is lower than that on the seaward side, saltwater is able to flow in a landward direction. The interface between fresh and saltwater is not a sharp but a zone of diffusion (Richter and Kreitler, 1993). It is the position of this interface relative to the locations and depths of coastal pumping wells that determines whether the water pumped is saline or fresh.

On the Gulf Islands, increased coastal residential and recreational development, combined with limited surface water sources, have placed increased demands on groundwater resources. Groundwater extraction in combination with high-density lot development has, in some areas (e.g. East Point on Saturna Island), resulted in unacceptable (with respect to aesthetics and human health) increases in the concentration of total dissolved solids (TDS) measured in groundwater samples (Allen and Suchy, 2001).

A further layer of complexity that characterizes the Gulf Islands is the presence of fractured sedimentary bedrock aquifers with associated fractures, faults and folds (Figure 3b). Fractures likely serve to further complicate saltwater intrusion processes. Unlike groundwater flow though unconsolidated sediments, flow through fractured bedrock follows discrete flow paths. The path taken by water as it flows though bedrock is defined by the aperture, orientation and interconnectedness of fractures that are hosted within the rock. Fracture zones, of which there are many on the Gulf, may provide preferential pathways along which water may flow Islands (Mackie, 2002). Because of their relatively high permeability, fracture zones are also prime targets for drillers in search of potable water. It is this high permeability that can lead to serious problems if coastal aquifers are over developed. Because fracture zones are desirable drilling

Figure 3b: Saltwater intrusion wedge in fractured rock (Suchy, 1998)

targets, several wells may tap the same fracture zone if properties are located in close proximity. The combined pumping of all wells may cause seawater to be drawn into all wells in a given area. Thus, over pumping of coastal wells drilled into fractured bedrock can result in significant landward migration of saltwater into an aquifer. The presence of discrete fractures can also be expected to result in neighbouring wells having completely different hydraulic and chemical characteristics, which may complicate the interpretation of spatial data.

1.2 Purpose

Due to the heavy reliance placed upon groundwater as a drinking water source, significant changes in water quality and quantity have the potential to affect a significant number of residents on the Gulf Islands of British Columbia. Water quality problems affecting residents of the more populated southern Gulf Islands are now beginning to appear on the more isolated northern Gulf Islands. The purpose of this groundwater study on Hornby Island was to collect and interpret hydrogeological and hydrochemical information for groundwater and surface water in order to evaluate the groundwater resource from the perspective of its quantity, quality and overall movement.

The study also aims to investigate the potential effect of island geometry on the chemical evolution of groundwaters, and to provide a benchmark for future studies tracking changes in water quality. Furthermore this study attempts to chemically define the mechanisms and delineate groundwater flow paths examining its evolution from inland recharge zone(s) through to coastal discharge zones.

1.3 Study Objectives

1. To acquire representative samples of groundwater and surface waters for Hornby Island and to assemble a chemical database.
2. To interpret these data in order to:

a) determine the spatial distribution and the nature of occurrence of various chemical constituents found dissolved in groundwater
b) identify local recharge and discharge zones on Hornby Island.
c) delineate flow regions on the basis of topography and geochemical trends.
d) explore potential processes that may be controlling natural groundwater evolution, in particular, salinization by saltwater intrusion.

1.4 Scope of Work

The specific tasks undertaken as part of this study included:

1. Collecting groundwater, surface water (fresh and ocean) and rainwater samples from a representative number of appropriately distributed sample locations.
2. Analyzing unprocessed analytical lab and field data using specialized groundwater modeling and plotting software.
3. Summarizing island geometry as it relates to the hydrogeology of Hornby Island.
4. Correlating geology to the occurrence of geochemical anomalies by analyzing the spatial distribution of such anomalies.
5. Summarizing analytical and field geochemical results into a geochemical database.

2.0 REGIONAL SETTING

2.1 Geology

Hornby Island is located within the present day Georgia Basin. The sedimentary rocks that comprise the Upper Cretaceous age Nanaimo Sedimentary Basin represent the predominant rock types (lithologies) that crop out on both the northern and southern Canadian Gulf Islands (Figure 1). The lateral extent of the five geological formations (Table 1) that underlie Hornby Island is variable, but well-exposed outcrop is present along most of the coastline (Figure 4, after Katnick, 2001).

The interpreted geology of the Gulf Islands has undergone modifications in recent years. This has direct bearing on hydrogeologic interpretations that are based heavily upon the structural and lithological investigations conducted by previous workers. For example, the original geological map for Hornby Island, produced by Muller and Jeletzski (1970), showed numerous large offset faults that define Mount Geoffrey. These faults conveniently explained the observed rock outcrop geometry, and the significant elevation difference between Mount Geoffrey and the low-lying flat to the west.

Unpublished M.Sc. research by Katnick (2001) in the Department of Earth Sciences at Simon Fraser University has revamped the Muller and Jeletzski geologic interpretation. Structures, originally interpreted as large offset faults, are re-interpreted as conformable contacts between the five formations that underlie Hornby Island (i.e., there are no faults and differential erosion has resulted in the observed outcrop pattern). The absence of major faults on the island suggests that groundwater flow will likely not be channeled significantly from one area of the island to another. Nor is there likely to be compartmentalization of groundwater flow resulting from any low permeability rocks associated with fault gouge along the fault plane (Caine et all, 1996; Allen and Michel, 1998, 1999). The absence of major faults is also likely associated with the relatively low

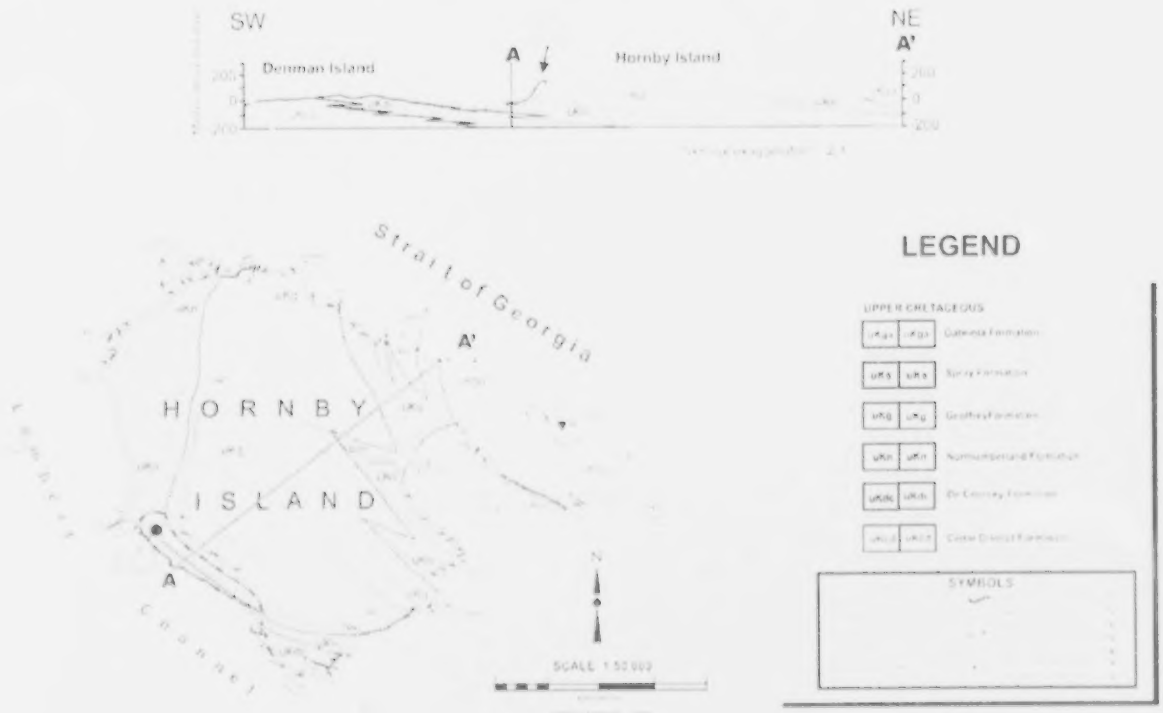

Figure 4. Geologic Map and Cross Section of Hornby Island (after Katnick, 2001)

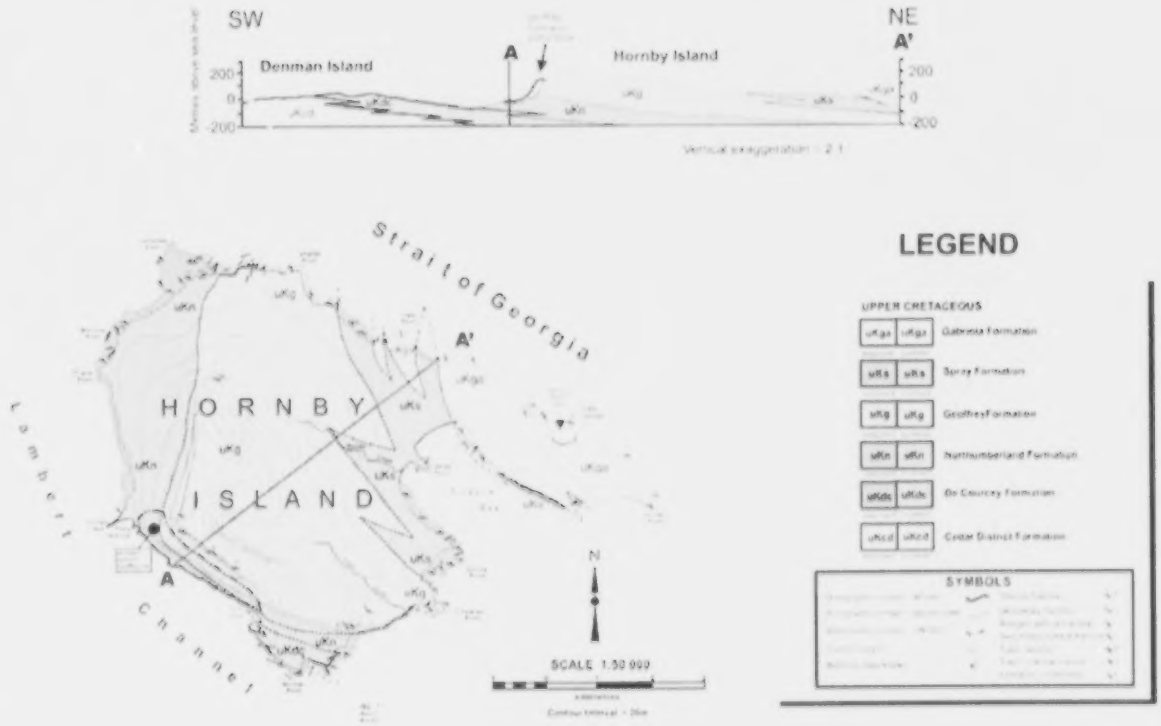

Figure 4. Geologic Map and Cross Section of Hornby Island (after Katnick, 2001)

Table 1: Hornby Island Lithology Summary (after Mustard, 1994)

Formation	Symbol	Description
Cedar District	CD	Lower Sequence begins with silty shale with a few fine-grained sandstone layers overlain by fine- to medium-grained sandstone with some interbeds.
De Courcy	DC	Mainly brown to grey sandstone, sub-rounded, fine- to medium-grained with minor feldspar, mica and carbonaceous material; base is mostly massive pebbly sandstone; very resistant to weathering.
Northumberland	N	Mostly interfingerings of sandstone and shale beds; beds higher in the succession are graded sandstone-siltstone-shale and are 2-15 cm thick.
Geoffrey	Ge	Well sorted sandstone with minor quantities of coarse conglomerate; shale beds are prominent throughout.
Spray	S	Grey mudstone and siltstone with 30-40% sandstone interbeds.
Gabriola	Ga	Predominantly thick-bedded coarse- to medium-grained sandstone; at Hornby Island >60 m of thick-bedded sandstone erosively overlain by >250 m of pebble conglomerate demonstrating a fining upwards sequence characterized by rare capping silty mudstone beds up to 10 cm thick

degree of fracturing observed on Hornby Island relative to the southern Gulf Islands, which themselves have undergone significant structural deformation. Notwithstanding the lower degree of structural deformation of Hornby Island, there are numerous minor fractures that can be expected to act as conduits for groundwater flow at a local scale.

2.1.1 Bedrock Geology

Hornby Island is underlain by bedrock of sedimentary origin that belongs to the Upper Cretaceous Nanaimo Group. Table 1 summarizes the basic lithology of each formation underlying Hornby Island (Mustard, 1994). In general, the sequence of rocks consist of alternating coarse (predominantly sandstone and conglomerate) and fine-grained (mudstone) units (Mustard, 1994). The fine-grained formations include the Cedar District, Northumberland and Spray formations, while the coarser-grained formations include the De Courcy, Geoffrey and Gabriola formations.

Low porosities (<5%) have been measured for the sandstone units comprising the Nanaimo Group (measurements made by industry in association with oil and gas exploration), and are related to extensive cementation and diagentic infilling by zeolites. The low porosities have resulted in coarse-grained bedrock units that have a much-reduced capacity to transmit water (i.e., a very low permeability). As such, water can be expected to flow primarily through the fractures, the mudstone units or along bedding contacts. This is consistent with observations by water well drillers on most islands who record higher yields, in fracture zones, within mudstone units, and at bedding contacts. Thus, while it is commonly held that mudstone units are aquitards or aquicludes, and that coarser-grained units (e.g., sandstones and conglomerates) are aquifers, these classifications are not necessarily representative of the Nanaimo Group rocks.

In general, the nature of the bedrock will have an important bearing on the pattern of groundwater movement (Figure 5) and the type of dissolved chemical constituents in groundwater (Section 4.2). Not only does each bedrock type have a characteristic porosity, and thus, permeability, but each will yield to structural deformation (i.e., fracturing) in different ways. Because lithology can potentially exert control on how fractures propagate through the rock column, contrasting mechanical properties between alternating sandstone, conglomerate and silt-mudstone units (or interbeds) may result in the concentration and/or increased intensity of fracturing within the finer grained units (Mackie, 2002).

The implication is that rock type and structure will have a significant bearing on groundwater flow. In complex geological systems, such as the Gulf Islands, where the rock type alternates between sandstone and mudstone and where the rocks have been subjected to different stresses associated with tectonic deformation, the groundwater flow patterns can be expected to be complex and difficult to characterize. At best, and without detailed studies on the hydrogeology, it is only possible to describe the overall geological attributes of the system, infer the general movement of groundwater, and characterize the chemical composition of groundwater based on large-scale trends.

2.1.2 Surficial Geology

The most recent period of glaciation (Fraser Glaciation, approximately 20 000 years B.P.) is generally responsible for depositing much of the surficial cover currently observed on the Gulf Islands (Clague, 1986). Due to the ongoing process erosion by wind and water, and mass wasting, much of this unconsolidated sedimentary cover has been removed, and is only present as a thin veneer on most islands. Local accumulations of sediments are sometimes observed at the bottom of valleys (Dixon-Warren, 1997).

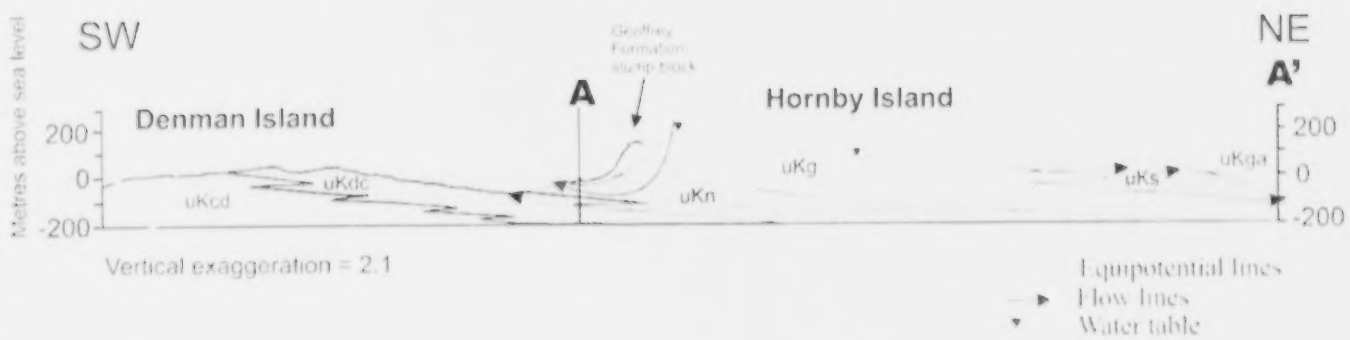

Figure 5. Theoretical hydrogeologic cross-section (Geology from Katnick, 2001)

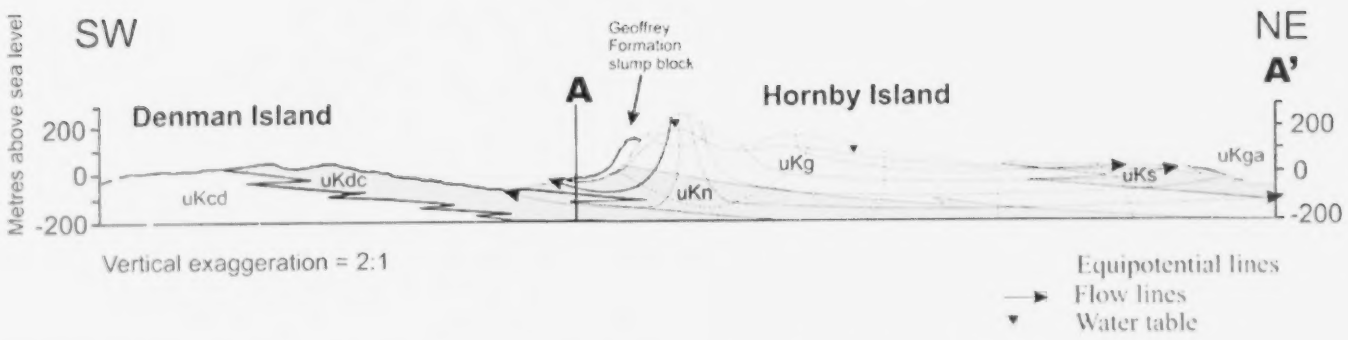

Figure 5. Theoretical hydrogeologic cross-section (Geology from Katnick, 2001)

The surficial geology of Hornby Island has not been mapped. As such, the interaction between deep and shallow groundwater systems may be difficult to interpret without knowing the spatial distribution and thickness of surficial cover. Therefore, a general understanding of the role that surficial cover plays in the groundwater system can potentially be obtained by observing the distribution of excavated wells and by observing groundwater geochemical trends. For example, the western flank of Mt. Geoffrey is a shear cliff. As such, it is reasonable to assume that the surficial cover at the foot of the cliff (talus) is probably characterized by a high permeability. It is also likely that this relatively high permeability cover allows for the rapid infiltration of surface runoff that cascades down the western flank of Mt. Geoffrey. Once in the subsurface, it may then interact with deeper groundwater systems.

In order to understand the interaction between shallow and deep groundwater systems, detailed surficial mapping would be of benefit.

2.2 Topography and Hydrogeology

The topography of Hornby Island is largely controlled by the underlying geology. The island is dominated by a central large forested upland area (Crown Land parcel) and flanked to the north, east and south by gentle slopes that end as sandy beaches, wave cut terraces and steep promontories upon meeting the ocean (e.g., High Salal). A large slump block of Geoffrey Formation sandstone defines the western flank of the island. This slump block defines a large forested bench that underlies the 300 m high Mt. Geoffrey and overlooks Shingle Spit and Ford Cove (Katnick, 2001).

Residential development is concentrated around Phipps Point, Galleon Beach, St. John Pt., Whaling Station Bay, Beaulah Creek, Tribune Bay, Sand Piper Beach, Downes Point and Ford Cove. These areas are characterized by moderate to low relief. The St. John Point and Whaling Station Bay areas, both

with moderate relief, small apparent local groundwater recharge areas, and relative high lot densities lend themselves to saltwater intrusion. These conditions are very similar to those observed by Allen and Suchy (2001) on the East Point Peninsula of Saturna Island. The similarity between East Point and the St. John Point – Whaling Station Bay area offers a means to directly compare the evolution of groundwater and the role of saltwater intrusion on the two islands.

The Strachan Valley, located within the Crown Land parcel, contains a few farms and residential lots. The Strachan Valley also holds a small beaver-dammed lake formed approximately two years ago. This lake is a relatively recent surface water feature on Hornby Island, and represents the only large body of freshwater on the island. The presence of this lake may have a significant impact on the ambient hydrogeologic conditions both in the vicinity of the lake and downgradient. For example, the lake may act to moderate the large seasonal fluctuations in groundwater levels observed on the island throughout the year. The long-term influence of this lake on groundwater requires further study.

In 1984, Chwojka conducted a preliminary review of groundwater conditions on Hornby Island. As part of this review, seven groundwater regions (Figure 6) were defined to facilitate discussion of groundwater in various parts of the island. These regions were defined primarily on the basis of topographic divides, density of wells, drainage systems, and shape and size of land masses, and correspond to :

1. Shingle Spit – Phipps Point
2. Manning Point – Collishaw Point
3. Shields Point
4. Whaling Station Bay
5. Spray Point - Tribune Bay
6. Dunlop Point – Downes Point
7. Norman Point – Ford Cove

Figure 6. Groundwater Regions (after Chwojka, 1984)

These groundwater regions may be loosely correlated with groundwater flow regions. However, it is important to recognize that topographic divides do not address subsurface inhomogeneities, such as fractures and bedding contacts, that may bypass topographic controls. Therefore, the use of chemical data will provided valuable constraints to the overall interpretation of the groundwater flow regions on Hornby Island.

2.3 Groundwater Usage

Residential and recreational property development on the Gulf Islands has historically been most intense along coastal exposures. Property development on Hornby Island is no exception to this general trend. There are several residential properties and a moderate sized farm located within the Strachan Valley and on the upland Crown Land Parcel. However, most development has been concentrated into high-density subdivisions (a relict of largely uncontrolled lot sub subdivision).

Groundwater supplies the majority of the potable water for local residents on Hornby Island. There are roughly 600 wells (both shallow and deep) on Hornby Island, which have been installed over the last 80 to 90 years, with a significant number installed over the last 30 to 40 years. The increase in the number of wells has been in response to the increase in the number of people living and vacationing on Hornby Island. Of these 600 wells, 120 were offered on a volunteer basis to be sampled during this study.

Most water supplies are derived from wells completed in the fractured bedrock. Hodge (1993) reported that yields for wells completed in bedrock were generally less than 0.3 L/s (5 Imp. gpm). These yields are in keeping with the general trend of relatively low well yields on the Gulf Islands. Some groundwater supplies are derived from the surficial deposits of unconsolidated sand and gravel, particularly in areas like Beulah and Ford Creeks (The Hornby Island Groundwater Pilot

Project, 1994). Residential wells average 36 m in depth, with a maximum depth of 107 m (FC-3). The shallowest well (dug well) was 2 m (sample ID: GA-9).

From a groundwater perspective, high-density residential lots and associated closely spaced private wells can aggravate problems related to water quality and quantity due to saltwater intrusion and well interference. Residential subdivisions such as Galleon Beach, Whaling Station Bay and Sand Piper Beach have water consumption that approach 83% of the estimated water available from local groundwater resources (Chwojka, 1989).

2.4 Hydrogeological Model

The chemical evolution of groundwater within the coastal, fractured, sedimentary bedrock aquifers of the Gulf Islands involves numerous chemical and physical processes that are superimposed onto complex and poorly understood subsurface flow regimes. The development of a hydrogeological model allows for the synthesis of geological, structural, hydrogeological, and hydrochemical data with the ultimate goal of describing this complex chemical and physical system. For the purposes of this study, island geometry forms the basis for defining an appropriate hydrogeologic conceptual model around which the geochemical results can be interpreted.

3.0 GEOCHEMISTRY: Methodology and Results

3.1 Methodology

3.1.1 Data Collection

128 water samples were collected during a field visit to Hornby Island in May, 2000. These samples were collected from a number of sources, which included private and community wells, surface waters (lake, swamp and streams), rainwater, and the ocean. The locations of all samples are shown in Figure 7. Samples that were submitted to Phillip Analytical Services for dissolved metal and anion analysis were collected in 250ml high-density polyethylene (HDPE) bottles. Metal samples were acidified to a pH of approximately 2 using measured aliquots of nitric acid supplied by the analytical lab. Anion samples were not preserved but were kept cool (at approximately 4°C) in environmental coolers. Sample collection and preservation protocols for this project are in accordance with the guidelines outlined in ASTM Standards on Environment Sampling (1994).

Sampling of surface waters employed grab sampling. Groundwaters from shallow dug wells and drilled wells were largely sampled from outside household taps or, in some instances, from taps located at the well. A few dug wells had to be sampled using a grab sampler. All sampling from residential and community wells was done with the express consent of the well owner and/or the community. Due to the inherent variability in the plumbing setup at each well, it was generally not possible to collect a sample before the water had passed through the pressure tank, but the water was allowed to flow for several minutes to ensure that the pump had cycled a few times. In a couple of cases, water was sampled after passing through a UV sterilization system, or directly from cistern holding system. Nevertheless, sample integrity does not appear to have been degraded. When necessary, samples were collected after filtration systems.

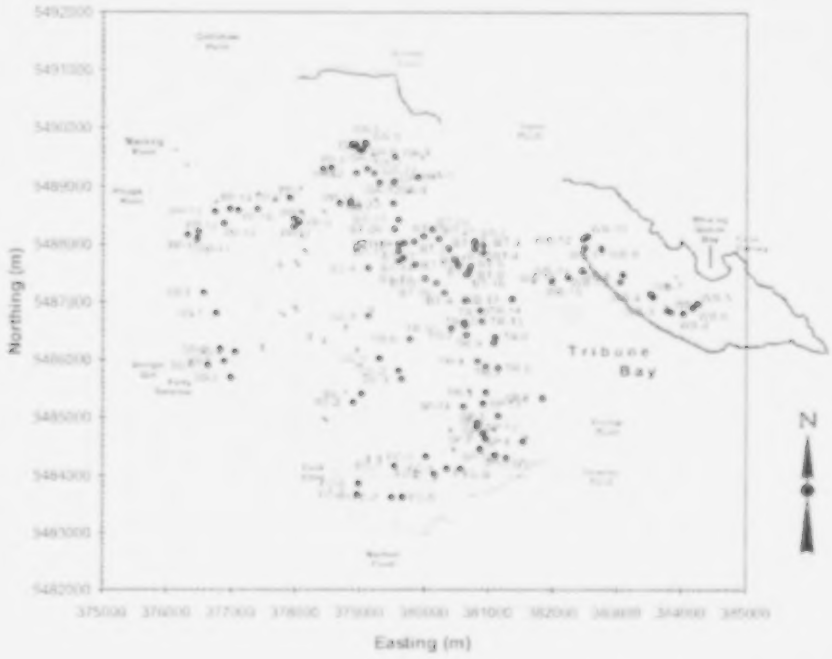

Figure 7. Sample location map

Field measurements of pH, temperature and total alkalinity were taken immediately upon collection of the sample. pH and temperature were measured using a Hanna HI 9023 temperature-compensated pH meter, and total alkalinity was measured using a Hanna HI 4811 field alkalinity test kit. Several titrations for total alkalinity were done to ensure repeatability. The average value is reported in Appendix A. Field measurement of these three parameters is necessary so as to record, as close as possible, the "in situ" chemical character of the water. Changes in temperature and the presence of atmospheric gases such as O_2 can result in significant changes in pH and total alkalinity values due to disruptions in the chemical equilibrium. Off gassing of some samples was observed, but gas composition and partial pressures were not obtained. It is not known if H_2S or CO_2 or possibly some other gas (methane?) was released (One resident claimed that his groundwater contained methane gas that could be ignited directly from a running tap). Other field parameters measured include conductivity and dissolved nitrate. These parameters were measured with a Hanna HI 9033 conductivity and Merckoquant nitrate test strips, respectively. Detection limits for all equipment used and tests performed by Phillip Analytical Services are summarized in Appendix A.

Three control samples were collected for this study. C-1 is the field blank that was obtained by passing distilled water through the field equipment (filters and beakers used for measurement of field parameters). C-1 was used as a check for both laboratory accuracy and proper field equipment rinsing procedures. A second control blank of distilled water may also be sent for analysis (i.e., one that represents the distilled water itself without having been put through the field sampling procedure). However, due to the financial restrictions, a control of this type was not used. It is expected that for the level of accuracy required for this sampling study, that the submission of a distilled water blank was not critical.

C-2 is an ocean water sample collected along Anderson Road on the north coast of Hornby Island (Figure 2). This sample is used to represent an end-member

water in the geochemical interpretation as groundwater normally can be expected to evolve toward an ocean water composition.

R2D2 is a rainwater sample that was collected in the Strachan Valley (Figure 2). This rainwater sample was collected off of a roof during a rainstorm event towards the end of the sampling period (May, 2000).

3.1.2 Data Analysis

All samples were sent to Phillip Environmental Services for analysis. An Inductively Coupled Argon Plasma Spectrophotometer (ICAP) was used to analyze for metals while pH, total hardness, and anions were analyzed according to procedures outlined in ASTM Standards on Environmental Sampling (1994) and the British Columbia Environmental Laboratory Manual. Detection limits are reported along with the chemical analysis results in Appendix A.

Upon receipt of the metal and anion analyses these unprocessed data were entered into SOLMINEQ® (Alberta Research Council, 1988). SOLMINEQ is a solution and chemical equilibrium software program that can be used to calculate chemical speciation (including the carbonate speciation, which is of primary importance to this work), charge balance errors, the saturation indices for various minerals, and the re-adjustment of the solution equilibrium to field conditions. Specifically, the solution is adjusted to provide the speciation and mineral equilibria at the measured field pH and temperature conditions rather than the lab conditions. Bicarbonate concentrations (HCO_3^-) are used later for plotting and interpretive purposes. These data were then entered into AquaChem® (Waterloo Hydrogeologic Inc., 1997) and Microsoft Excel (7.0) for the plotting of Piper diagrams, bivariate graphs, and bicarbonate – pH graphs. To construct a Piper plot, the relative concentrations of three cations and three anions (expressed in milliequivalents) are calculated. Typically, Ca, Mg and Na are the cations, and HCO_3, Cl and SO_4 are the anions, although other combinations may be useful for

different types of studies. For each sample, the cation composition is plotted on the right triangle and anion composition on the left, and the sample points are projected onto the diamond. Bivariate plots (or scatter plots) show the relative concentrations of two constituents for different samples. These plots are useful for visualizing trend in the data, and for illustrating key groundwater evolutionary processes.

3.1.3 Charge Balance Error

Another important calculated value that must be considered is the charge balance error (CBE) (Freeze and Cherry, 1979):

$$CBE = \frac{\sum zm_c - \sum zm_a}{\sum zm_c + \sum zm_a} x100 \qquad (3.1)$$

where z and m represent the ionic charge and molality (defined as moles/kg), respectively, of each ionic analyte. The charge balance error is one method used to assess the integrity of a sample's analysis because all solutions should be electrically neutral. For an analysis to be considered "good" it should fall in the range of ±5%. A few samples in this study have CBEs greater than ±5% (Table 2). High CBEs may indicate a problem with the lab analysis, or that one or more ion present was not analyzed. It must be noted that determining the magnitude of CBE is dependent on capturing the charge contributions of each ion. The absence of a given ion will result in an increase or decrease in CBE depending on the concentration of the missing ion and on its associated ionic charge. If an ion with a high concentration and ionic charge is not included in the analysis then the associated CBE will be large. On the other hand, if an ion with a low concentration and low ionic charge is missed in the analysis, then the associated impact on CBE will be small. As such, it is very important to capture the dominant ionic species in a sample. Another consideration is that for samples with low concentrations of dissolved species, the effect of a small error in concentration is amplified.

Table 2. Charge Balance Error (CBE) Summary for all Samples

Sample ID	Laboratory Charge Balance Error (%)*	Calculated Charge Balance Error (%)**						
BT-01	20.54	15.11	GA-09	1.57	4.73	TR-05	2.41	5.13
BT-02	3.08	11.66	GA-10	1.72	9.07	TR-06	9.46	18.74
BT-03	-38.40	-23.87	GA-11	1.37	5.99	TR-07	3.04	9.15
BT-04	-41.04	-51.56	GA-12	5.22	11.92	TR-08	6.46	3.40
BT-05	3.12	8.98	GA-13	6.41	12.53	TR-09	3.75	5.34
BT-06	1.56	9.11	PP-01	1.83	1.36	TR-10	2.62	4.03
BT-07	1.23	6.60	PP-02	5.03	12.73	TR-11	3.27	9.69
BT-08	-1.16	6.21	PP-03	9.44	9.68	TR-12	-8.91	1.54
BT-09	0.67	7.03	PP-04	3.25	9.69	TR-13	14.29	3.00
BT-10	1.91	9.28	PP-05	5.00	11.03	TR-14	3.02	8.48
BT-11	2.29	8.58	PP-06	9.34	15.16	WB-01	6.29	10.77
BT-12	3.29	10.55	PP-07	2.90	3.34	WB-02	4.09	6.74
BT-13	-1.67	5.63	PP-08	2.89	8.12	WB-03	-0.99	-0.70
BT-14	4.42	10.47	PP-10	5.54	10.77	WB-04	8.60	14.53
BT-15	3.74	7.06	PP-11	1.47	9.58	WB-05	5.45	11.08
BT-16	-2.06	3.89	PP-12	4.04	12.12	WB-06	4.10	10.80
BT-17	2.10	8.39	PP-13	19.93	23.32	WB-07	4.07	8.14
BT-18	6.18	6.65	PP-14	4.72	12.25	WB-08	1.49	9.34
BT-19	4.84	4.52	PP-15	-6.93	-2.15	WB-09	-1.14	7.04
BT-20	5.72	12.37	PP-16	1.37	6.14	WB-10	1.19	7.47
BT-21	5.21	12.34	PP-17	2.38	9.13	WB-11	2.55	5.46
BT-23	8.80	14.43	PP-18	6.18	11.66	WB-12	4.97	9.38
BT-24	2.87	9.66	SP-01	4.05	7.17	WB-13	-0.03	6.62
BT-25	4.87	11.66	SP-02	6.97	12.94	WB-14	3.02	8.60
BT-26	2.14	6.19	SP-03	5.82	9.72	WB-15	10.71	16.64
BT-27	1.66	1.28	SP-04	8.60	11.41	WB-16	1.23	6.33
C-01	-79.40	-79.76	SP-05	3.27	10.13	WB-17	5.39	11.21
C-02	-2.11	-2.21	SP-06	2.28	6.78			
R2D2	-57.59	-57.12	SP-07	3.74	11.39			
CL-01	1.46	5.05	SP-08	8.43	8.26			
CL-02	17.16	20.20	SP-09	1.73	7.59			
CL-03	13.68	15.06	SP-10	3.33	6.85			
CL-04	10.56	13.68	SP-11	1.65	5.59			
FC-01	4.36	9.96	SP-12	0.02	3.61			
FC-02	5.59	9.11	SP-13	-0.54	-0.68			
FC-03	5.69	13.76	SP-14	3.90	11.47			
FC-04	3.09	6.86	SS-01	9.70	9.88			
FC-05	1.61	7.50	SS-02	11.06	10.85			
FC-06	0.80	6.31	SS-03	25.29	31.72			
FC-07	6.99	11.37	SS-04	4.30	7.92			
FC-08	-0.02	4.90	SS-05	9.87	10.17			
FC-09	1.81	7.86	SS-06	6.50	8.30			
GA-01	0.98	0.11	SS-07	6.73	10.60			
GA-02	2.80	7.95	SV-01	5.39	11.74			
GA-03	4.79	11.51	SV-02	19.50	16.35			
GA-04	1.74	9.90	SV-03	6.71	11.94			
GA-05	0.94	8.57	TR-01	-1.23	4.22			
GA-06	0.65	8.14	TR-02	2.80	4.04			
GA-07	2.76	9.48	TR-03	2.67	10.31			
GA-08	3.79	10.46	TR-04	9.76	13.24			

* Laboratory Charge Balance Error calculated using raw lab results.
** Calculated Charge Balance Error calculated using output from Stiemberg

Table 3. Samples Accepted or Rejected on the Basis of CBE

	Sample ID	Lab Charge Balance Error (%)	Calculated Charge Balance Error (%)
Samples with ±10%<E<±14.99%	CL-03	13.68	15.66
	CL-04	10.56	13.68
	SS-02	11.06	10.85
	TR-13	14.29	3.90
	WB-15	10.71	16.84
Samples with E>±15%	*BT-01	29.54	35.11
	*BT-03	-30.40	-23.87
	*BT-04	43.94	51.86
	**C-01	-79.40	-78.70
	*CL-02	17.16	5.65
	*PP-13	19.93	23.32
	***R2D2	-57.59	-57.12
	*SS-03	25.29	31.72
	*SV-02	16.50	16.35

*Discarded Samples

**Field Blank (not discarded)

*** Rainwater (not discarded)

The integrity of the data collected for this study was determined by comparing both the calculated and lab CBE. Table 2 summarizes the CBEs for all samples, while Table 3 summarizes suspect and unacceptable samples. The distinction between suspect and unacceptable CBE was based on CBE ranges. Most labs take a CBE of <±5% to be acceptable (Freeze and Cherry, 1979). CBE values in the range ±10% to ±14.99% were considered to be suspect, while values in excess of ±15% were deemed unusable for the purposes of this study. The exceptions to these criteria were the control sample (C-1) and the rainwater sample (R2D2). These samples had calculated CBEs of –78.70% and –57.12%, respectively. These CBEs are not unexpected because the concentration of dissolved solids is very low, and as discussed above, analytical error and method sensitivity can result in significant imbalances between the anion and cation totals used in calculating the CBE.

The following is a summary of the methodology and analytical lab results obtained during this study. The raw lab results were processed using SOLMINEQ® and AquaChem®, and then partitioned into groups based on the location from which samples were collected.

Four groups will be discussed, and the chemical characteristics summarize the results found in Appendix A:

1. Control Samples
2. Surface Water
3. Spring Water
4. Groundwater

3.1 Control Samples

Control samples C-1, C-2 and R2D2 represent the field-blank, ocean water and a rainwater samples, respectively (Figure 8). Sample C-1 is the field blank and represents the quality assurance and quality control (QA/QC) required by the sampling guidelines outlined in ASTM Standards on Environment Sampling

(1994). As such, this sample has common ion concentrations that are generally below detection limits. Na and Ca are the only exceptions, with low respective concentrations of 0.54 mg/L and 0.08 mg/L. The pH is 6, and total alkalinity and conductivity are 15 mg/L (as HCO_3^-) and 3.4 μS/cm, respectively.

Samples R2D2 and C-2 were sampled to represent end-member compositions for geochemical evolution analysis. The rainwater sample, R2D2, represents the "ideal" starting composition for infiltration water, while C-2 represents ocean water (chemically evolved). Being end-member compositions the respective chemistries are markedly different.

R2D2 is similar in composition to the field blank (C-1). Na, Ca, Mg and SO_4^{2-} were all low at concentrations of 0.57 mg/L, 0.23 mg/L, 0.15 mg/L and 1.1 mg/L, respectively. Cl was the only common ion below detection limits in this sample. HCO_3^- is elevated in this rainwater sample, with a value of 17.01 mg/L. It is unclear why the rainwater sample has elevated HCO_3^-. Sample contamination during collection and the naturally elevated TDS levels common in coastal precipitation, due to sea spray all contribute to variations in the chemical composition of a rainwater sample. As well, geographic location for rainwater collection can affect its chemical composition. For this reason, R2D2 may not be representative of natural rainfall.

C-2 (seawater sample) has a very high conductivity (34300 μS/cm), as expected, extremely high concentrations of the common ions. Cl is the dominant anion at 16000 mg/L, followed by Na at 8940 mg/L and SO_4^{2-} at 2320 mg/L. Ca and Mg were also high at 265 mg/L and 866 mg/L, respectively.

3.2 Surface Waters

The surface water samples collected during this study were obtained from natural (CL-1 and CL-2) and excavated ponds (SV-3 and SP-3), a swamp (WB-2), and two creeks (CL-3 and CL-4). The SV and CL sample groups were collected from

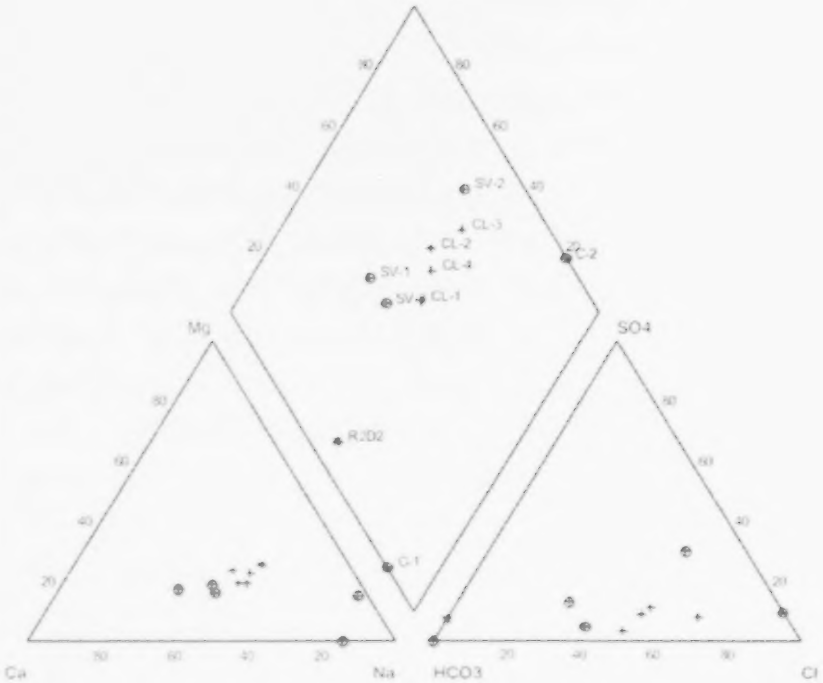

Figure 8. Piper plot of surface waters and controls samples

the Strachan Valley and Crown Land Parcel, respectively. The Strachan Valley is situated on the southwest flank of the Crown Land Parcel. All of these surface samples plot near the center of the Piper diamond (Figure 8). For the four CL samples, pH, total alkalinity (as HCO_3^-) and conductivity values vary within a small range. pH ranges from 5.8 to 6.4, total alkalinity is low and ranges from 11 to 24 mg/L, and conductivity is also low with a range of 67.7 to 86 μS/cm. These values are in keeping with chemically immature, or juvenile, waters. Likewise, major ion concentrations are low and vary within a small range: Na does not exceed 11.3 mg/L and Ca ranges from 5.51 to7.3 mg/L. Cl is the dominant ion, and concentration ranges from 18 to 15 mg/L. SV-2 (a sample from the beaver-dammed lake) was discarded due to its high calculated CBE (+16.35%), and samples CL-3 and CL–4 were identified as being suspect (i.e., $\pm 10\% < CBE < \pm 14.99\%$). Because CL-3 and CL–4 do not appear to plot unusually in Figure 8, they are included in the interpretation of groundwater evolution.

3.3 Spring Waters

Only one spring water sample was collected (SV-1). This sample, like the others in the SV sample group, was collected in the Strachan Valley. This valley is located on Mount Geoffrey, a potential recharge zone. The neutral pH (7.1), low total alkalinity (45 mg/L), and low concentrations of major dissolved ions hint at a shallow spring supplied by surface run-off. This statement is based upon the similarities between the chemistries of SV-1, SV-2 and SV–3 (SV-2 and SV–3 are surface samples) (Figure 8). SV-2 was discarded due to a high CBE.

3.4 Groundwater

The composition of groundwater on Hornby Island is variable. Three distinct compositions can be identified using the Piper plot (Figure 9):

1) chemically immature groundwaters, which plot near the center of the Piper plot,

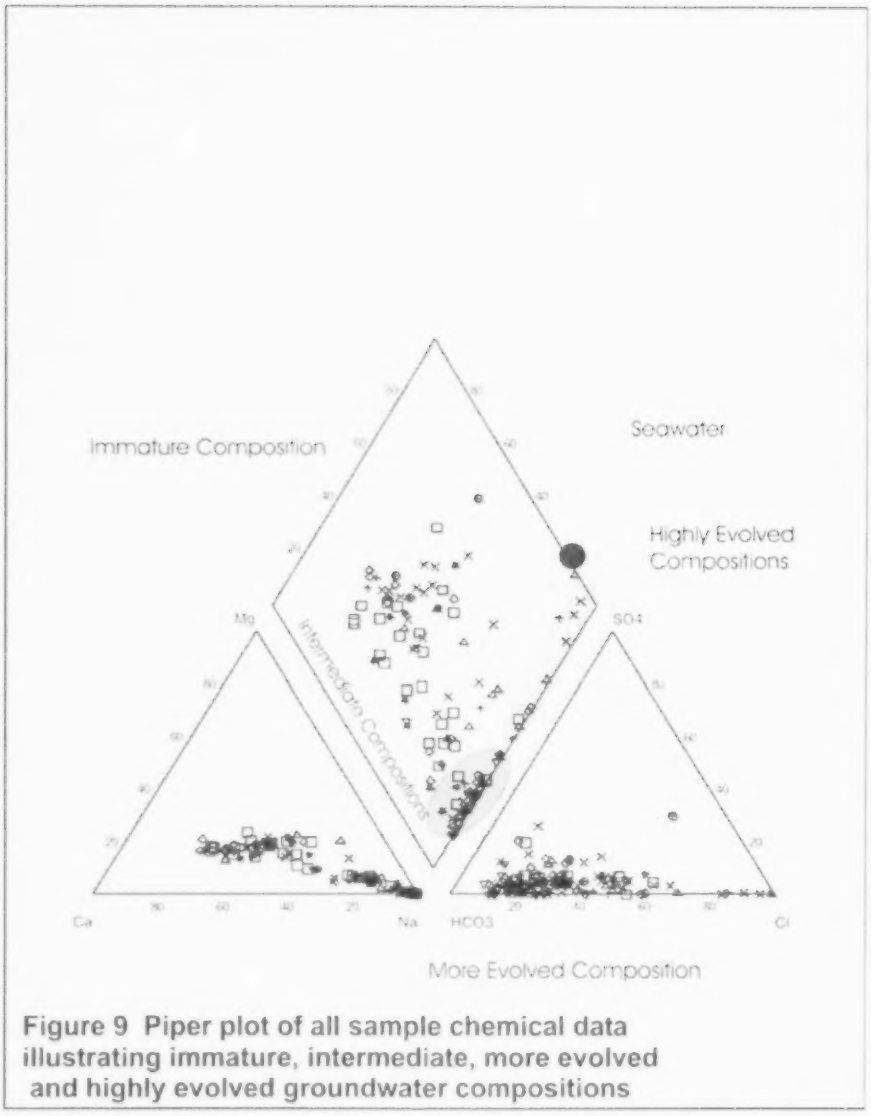

Figure 9 Piper plot of all sample chemical data illustrating immature, intermediate, more evolved and highly evolved groundwater compositions

2) chemically more evolved groundwaters, which plot directly below the immature waters near the bottom left edge of the Piper diamond, and
3) highly evolved groundwater, which plots near ocean water.

A number of samples have an intermediate composition, and plot between these type waters. In addition to their different plotting positions on the Piper plot, which reflects the composition of the sample, these samples have significant differences in measured field parameters and total concentrations of dissolved species. It is with these additional parameters in mind that groundwater compositions were categorized on the basis of being immature, more evolved or saline. The processes by which groundwaters evolve, which are reflected in the compositions of intermediate groundwaters, are described under General Groundwater Evolution (see Section 4.0).

The sample group PP (Phipps Point) will be used as a representative group for the purpose of summarizing the general chemistry of immature and evolved groundwaters (Figure 10). The Piper plots for all sample regions are provided in Appendix B. Chemical anomalies, involving elevated levels of dissolved species such as manganese (Mn), boron (B), fluoride (F) and sulphate (SO_4^{2-}), are summarized separately.

3.5 Chemically Immature Groundwater Compositions

From the PP sample group, samples PP-1, PP-5, PP-6 and PP-18 appear to plot as immature groundwaters (i.e., near the center of the diamond in Figure 10). These immature groundwaters were sampled from wells completed over a range of depths (i.e., from dug, shallow, mid-depth and deep wells). In general, these waters have similar pH, electrical conductivity (EC), total alkalinity, and major ion concentrations to the surface and rainwater samples. pH ranges from 6.7 to 7.6, with the deepest well recording one of the lowest pH values. This result is unusual because generally the deep wells (40-110m for this study) have pH

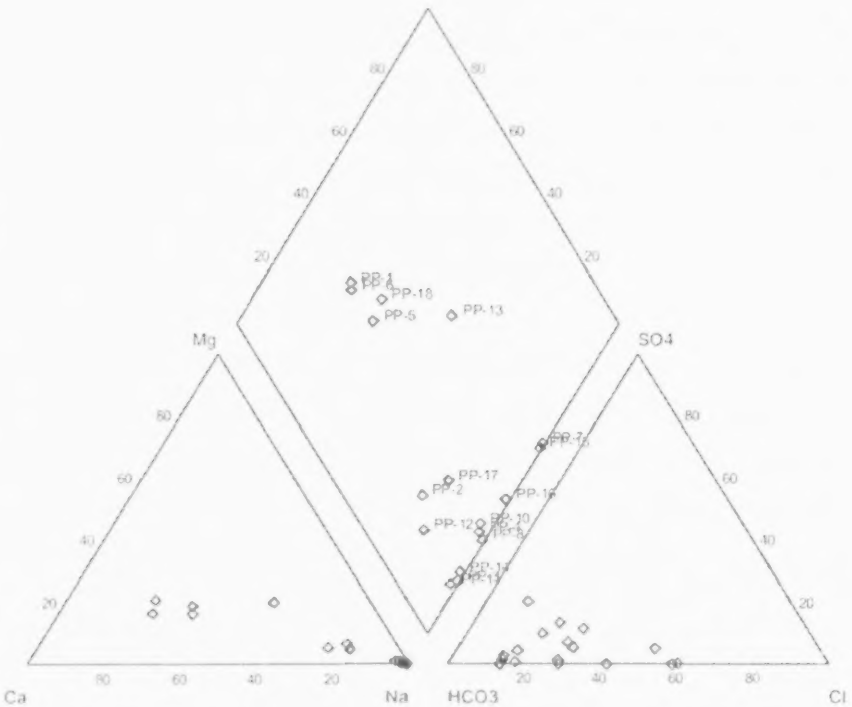

Figure 10. Representative groundwaters from the Phipps Point flow region

values in the range 8 to 9. Total alkalinity ranges between 48 and 120 mg/L (as HCO_3^-), while EC ranges between 236 μS/cm and 106 μS/cm. Concentrations of major ions are generally slightly elevated compared to those measured in surface water samples. This is not unexpected as it is assumed that waters collected from mid- to deep wells have been resident in the subsurface for a longer period of time, and therefore, have had sufficient time to dissolve minerals.

3.6 Chemically More Evolved Groundwater Compositions

Samples PP-2, PP-3, PP-4, PP-7, PP-8, PP-10, PP-11, PP-12, PP-14, PP-15, PP-16 and PP–17 appear to represent more highly evolved groundwaters (note sample PP-13 was discarded due to its high CBE). The average depth for these wells is approximately 30 m. These samples plot beneath the immature groundwaters along the lower edge of Piper diamond (Figure 10), and are characterized by relatively high pH (7.3-9.1) and EC (198-1568 μS/cm) values. EC averages 527.5 μS/cm, which is higher than that measured in immature groundwaters. Major ion concentrations vary markedly. For example, Na varies from 14.1 to 400 mg/L, Ca varies from 0.8 to 12.9 mg/L and Mg varies from 0.12 to 2.66 mg/L, suggesting a range of total dissolved solids.

3.7 Anomalous Concentrations

In order to examine the occurrence of anomalous concentrations of dissolved species, it is necessary to define acceptable limits. For the purposes of this study, the Canadian Drinking Water Guidelines are used for comparison. While incomplete in many respects, these guidelines offer the only means for assessing water quality. Table 4 shows the Canadian Drinking Water Guidelines and the United States Drinking Water Guidelines. Several constituents have no reported limit. It is important to note that most chemical constituents considered in this study were analyzed at detection limits that are lower than those reported in the Drinking Water Guidelines. For example, the minimum detection limit (MDL) for F (Table 5) was 0.1 mg/L and the guideline indicates that concentrations less than

Table 4. Canadian Drinking Water Guidelines

		Canada	United States
Physical Parameters	Alkalinity	30-500 mg/L	-
	Hardness	<120 mg/L	-
	pH	6.5-8.3 units	-
	TDS	<1000 mg/L	
Anions	Fluoride	1.5 mg/L	4.0
	Chloride	<=250.0 mg/L	-
	Nitrate	45.0 mg/L	10.0
	Nitrite	3.2 mg/L	1.0
	Sulphate	<=500.0 mg/L	-
Cations	Aluminum (10)		-
	Antimony (10)		0.006
	Arsenic (8)	0.025 mg/L	0.05
	Barium	1.0 mg/L	2
	Beryllium (10)		0.004
	Boron (8)	5.0 mg/L	-
	Cadmium	0.005 mg/L	0.005
	Calcium (13)		-
	Chromium	0.05 mg/L	-
	Cobalt (10)		-
	Copper	<=1.0 mg/L	1.3
	Iron	<=0.3 mg/L	-
	Lead	0.01 mg/L	0.015
	Manganese	<=0.05 mg/L	-
	Nickel (10)		-
	Selenium	0.01 mg/L	0.05
	Silver (13)		-
	Sodium	<=200 mg/L	-
	Thallium	-	0.002
	Uranium (10)	0.1 mg/L	-
	Zinc	<=5.0 mg/L	-

Results expressed as milligrams per liter (mg/L)

TDS: Total Dissolved Solids

Footnotes

8. Interim water guideline

10. Guideline under review for addition to, or possible changes to, the current value

13. Parameters identified as not requiring a numerical guideline

Table 5: Range of Concentration for Dissolved Constituents and Number of Samples above the Canadian Drinking Water Guidelines

DISSOLVED CONSTITUENT	DRINKING WATER GUIDELINE (mg/L)	DETECTION LIMIT (mg/L)	RANGE	# SAMPLES ABOVE DWG
Flouride	**1.5**	**0.1**	**<0.1 - 6.02**	**23**
Bromide		<1.0	<1.0 - 63	
Chloride	**<=250**	**1**	**<1.0 - 16000**	**9**
Nitrate-N	45		N.D. (test strip)	
		0.02	<.02 - .17 (7 samples)	
Sulphate	500	1	<1.0 - 2320	1
Aluminum		0.02	<.02 - .29	
Antimony		0.05	ALL <.05	
Arsenic	0.025	0.05	ALL <.05	
Barium	1	0.001	.001 - 5.45	1
Beryllium		0.0002	ALL <.0002	
Bismuth		0.05	ALL <.05	
Boron	5	0.008	<.008 - 4.91	
Cadmium	0.005	0.002	ALL <.002	
Calcium	200	0.05	.08 - 378	2
Chromium	0.05	0.005	ALL <.005	
Cobalt		0.005	ALL<.005	
Copper	1	0.005	<.005 - .744	
Iron	**0.3**	**0.005**	**<.005 - 14.6**	**18**
Lead	0.01	0.03	<.03 (ALL) - .07(1)	
Magnesium	50	0.05	<.05 - 866	1
Manganese	**0.05**	**0.001**	**<.001 - 2.48**	**32**
Molybdenum		0.005	<.005 (ALL) - .001 (1)	
Nickel		0.008	<.008 (ALL) - .023 (1)	
Phosporous		0.1	<.1 - 4.5	
Potassium		1	<1 - 300	
Selenium	0.01	0.03	ALL <.03	
Silver	0.05	0.01	<.01 (ALL) - .03 (1)	
Silica				
Sodium	**200**	**0.05**	**.54 - 8940**	**13**
Strontium		0.001	.005 - 36.2	
Sulphur		0.1	<.1 - 767	
Tellurium		0.05	ALL <.05	
Thallium		0.03	ALL<.03	
Tin		0.02	ALL <.02	
Titanium		0.003	<.003 (ALL) - .004 (1)	
Vanadium		0.005	ALL <.005	
Zinc	5	0.005	<.005 - 1.05	
Zirconium		0.005	ALL <.005	

1.5 mg/L are acceptable. However, for both arsenic (As) and lead (Pb), the minimum detection limit (MDL) is above the drinking water limits, so it is impossible to determine if the measured concentrations meet the drinking water guidelines. Consideration should therefore be given to the MDLs when evaluating anomalous concentrations of dissolved species.

Unusually high levels of boron, manganese and fluoride have been reported by some local residents on Hornby Island, and concern about these concentrations was expressed. The current limits for B, Mn, and F have been set at 5.0 mg/L (interim guideline), ≤0.05 mg/L and 1.5 mg/L, respectively.

- No samples exceeded the current limits for dissolved B although six samples in the Whaling Station Bay area (WB) reported concentrations in excess of 1.21 mg/L, and one sample reported a concentration of 4.91. The average B concentration (0.63 mg/L) is well below the maximum limit outlined in the Canadian Drinking Water Guidelines.

- Dissolved Mn averages 0.083 mg/L with a maximum of 2.48 mg/L (WB-15). In total, 32 samples exceeding the Drinking Water Guidelines of 0.05 mg/L for Mn.

- Fluoride (F) concentrations exceeded the 1.5 mg/L Drinking Water Guideline in 23 samples that were obtained from wells over a broad range of areas (sample groups SP, FC, TR, BT, GA, WB, SS and PP). The maximum F level is 6.02 mg/L (sample GA-4). Several samples were below detection limits.

In addition to B, Mn and F, chloride (Cl) was found to exceed Drinking Water Guidelines in 9 wells, sodium (Na) in 13 wells, and iron (Fe) in 18 wells.

Hydrogen sulphide (H_2S) gas was also prevalent in many waters. During sampling, many samples had an obvious rotten egg smell, characteristic of the

presence of H_2S. It is important to note however that even small amounts of H_2S can be smelled, and that this gas is generally not harmful at low concentrations.

In order to nature and occurrence of the various dissolved constituents and to attempt to relate these to the geology and hydrogeology of an area, it is sometimes possible to contour the concentrations of each constituent and show them on a map. In order to contour the chemical data, the UTM coordinates for each sample location, as well as the concentration of the constituent of interest, was input into SURFER (Golden Software, version 6.0). This software package employs an interpolation algorithm to determine the concentration at points that are at intermediate positions between the known values and generates concentration contours from the results. Sample distribution is an important consideration in attempting to interpolate data, therefore, the results of this type of visual analysis should be viewed with caution. As well, the contours extend beyond the island imprint by virtue of the rectangular grid that is employed for contouring.

Contour maps showing the spatial distribution of each of barium (Ba), boron (B), calcium (Ca), chloride (Cl), fluoride (F), iron (Fe), manganese (Mn) and sodium (Na) are shown in Appendix C.

4.0 DISCUSSION

4.1 Major Geochemical Processes

There are three major natural processes, in addition to chemical reactions (such as oxidation-reduction reactions) that commonly contribute to the observed chemistry of groundwaters. These processes may act alone, but are more commonly observed to work in concert with one another:

1. Dissolution of Minerals
2. Cation-Exchange
3. Simple Mixing

4.1.1 Dissolution of Minerals: with Consideration of the Carbonate System

The chemical weathering of rock by water results in the liberation of numerous dissolved ion species (e.g., Na^+, Ca^{2+}, SiO_2, and SO_4^{2-}...). It is by this process that relatively juvenile surface water compositions gradually become enriched in total dissolved solids. The rate and degree to which enrichment occurs is dependent on a number of factors including, 1) the solubility of the minerals present, 2) the temperature and pH of the water, 3) the amount of surface area available for the water to react with minerals comprising the aquifer (fractured rock in the case of the Gulf Islands), and 4) the amount of time that the water is in contact with the minerals (i.e., the residence time).

Carbonate equilibria exercise a dominant control on the evolution of groundwater. Carbonate equilibria pertain to the complex interplay between CO_2 (gas), carbonic acid (H_2CO_3), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) in aqueous solution. These species are related to each other by the following equation:

$$CO_2(g) + H_2O(l) = H_2CO_3\,(aq) = HCO_3^-\,(aq) + H^+ = CO_3^{2-} + H^+ \qquad (4.1)$$

Subtle shifts in the concentration or fugasity (f) of CO_2 (g) can result in significant perturbations in the amount of HCO_3^- and CO_3^{2-} present in a groundwater.

The availability of CO_2 (i.e., as measured by the partial pressure of CO_2 (pCO_2)) dictates whether or not a groundwater evolves under open or closed conditions. pCO_2 for the atmosphere is $10^{-3.5}$ Bar, while pCO_2 is slightly higher in the soil horizon due to the production of CO_2, and is generally about $10^{-1.5}$ Bar. Common sources of CO_2 gas in the shallow subsurface include the metabolic gases of soil bacteria, root respiration, and atmospheric gases trapped between soil particles.

Open system evolution of groundwater involves a constant source of CO_2 during dissolution of mineral species, while closed system evolution involves the eventual isolation of a groundwater from a source of CO_2. Open system conditions result in a moderate increase in HCO_3^- with an accompanying increase in pH. At the pHs commonly encountered in groundwater (pH=6.5-9.1), HCO_3^- is the dominant carbonate species present. The lack of a CO_2 source, as is the case with closed system conditions, means that the carbonate equilibrium is shifted to the left in equation (4.1) in order to replace H_2CO_3 that is consumed by mineral dissolution reactions (especially calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). When H_2CO_3 is consumed, there can be a significant increase in pH.

The dissolution of carbonate minerals is generally considered to be a primary source of Ca^{2+}, HCO_3^-, and possibly Mg, in groundwater. This composition is reflected on a Piper Plot. For example, in sample area BT (Figure 11), several samples plot in the center of the diamond. These samples include BT-1, BT-5, BT-12, BT-13, BT-15, BT-23 and BT-27. The water is Ca-HCO_3 type, reflecting simply the dissolution of carbonate minerals, which corresponds with an immature groundwater composition.

In the absence of other minerals, the concentrations of Ca, Mg and HCO_3^- will increase until the groundwater becomes saturated with respect to calcite and dolomite is achieved and dissolution ceases. The low concentrations of Mg in

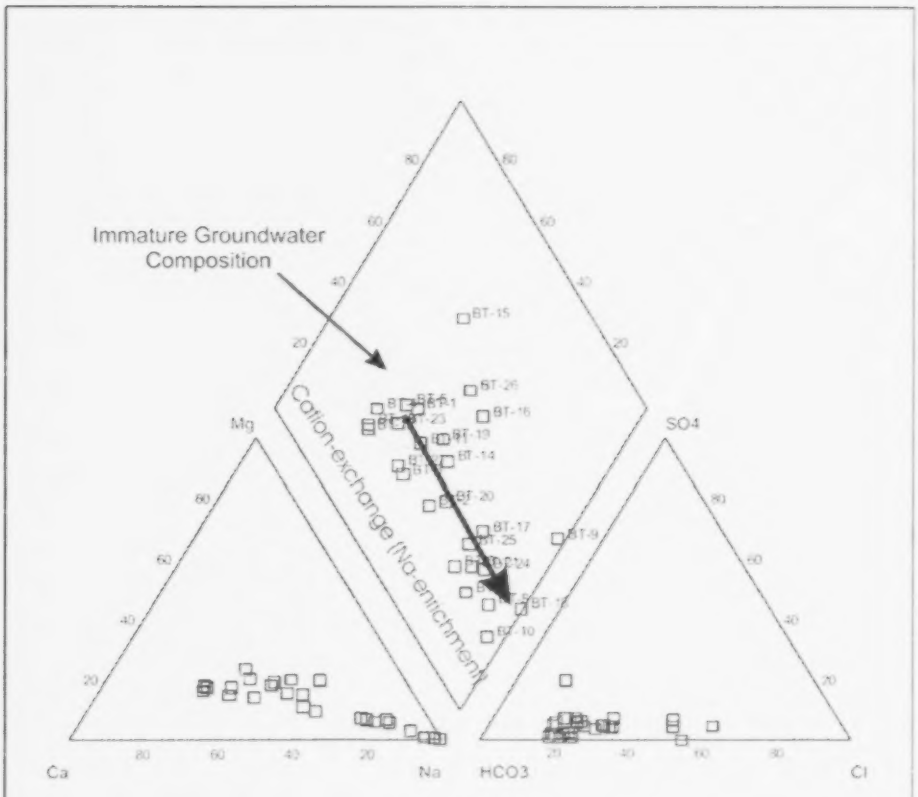

Figure 11. Illustration of the cation exchange process (sample group BT)

water samples collected on Hornby Island, similar to low concentrations on Saturna Island (Allen and Suchy, 2001), probably indicate that the dissolution of dolomite is of minor importance.

Figure 12 is a graph of HCO_3^- versus pH for all samples differentiated on the basis of their sample area. The position of the lines that identify calcite and dolomite saturation were determined at 25°C for water that is initially ion-free (free of other constituents). If other ions are present in the water, then these lines shift to the right. This implies that in a groundwater with other constituents present, more calcite and/or dolomite could be dissolved before saturation is attained. Salinization is one process that can result in relatively high ionic strength solutions.

4.1.2 Cation Exchange

Cation exchange is a process that commonly occurs on clays and other minerals that harbour a negative charge on their surfaces, and can be responsible for significant increases in the levels of dissolved Na and simultaneous decreases in the levels of dissolved Ca and Mg. Immature groundwaters in sedimentary aquifers are commonly characterized as Ca-HCO_3 in composition. However, if a suitable exchange media is present in the subsurface (e.g., mudstone interbeds and stringers within otherwise coarse-grained materials) there can be a significant increase in the amount of Na present, due to cation exchange. The degree to which the exchange of Ca (and Mg) with Na occurs is dependent on the pH, temperature, surface area available for exchange, the cation exchange capacity (CEC) of the exchange media (e.g., CEC varies for different clay minerals mudstone), residence time, and the concentration of the solutions involved. Elevated pHs (i.e., lower H^+ concentrations), large surface areas and long residence times favour the cation-exchange process (Stumm and Morgan, 1996). Based on these criteria, it would be expected that chemically mature waters that have evolved for extended periods of time would tend to show the

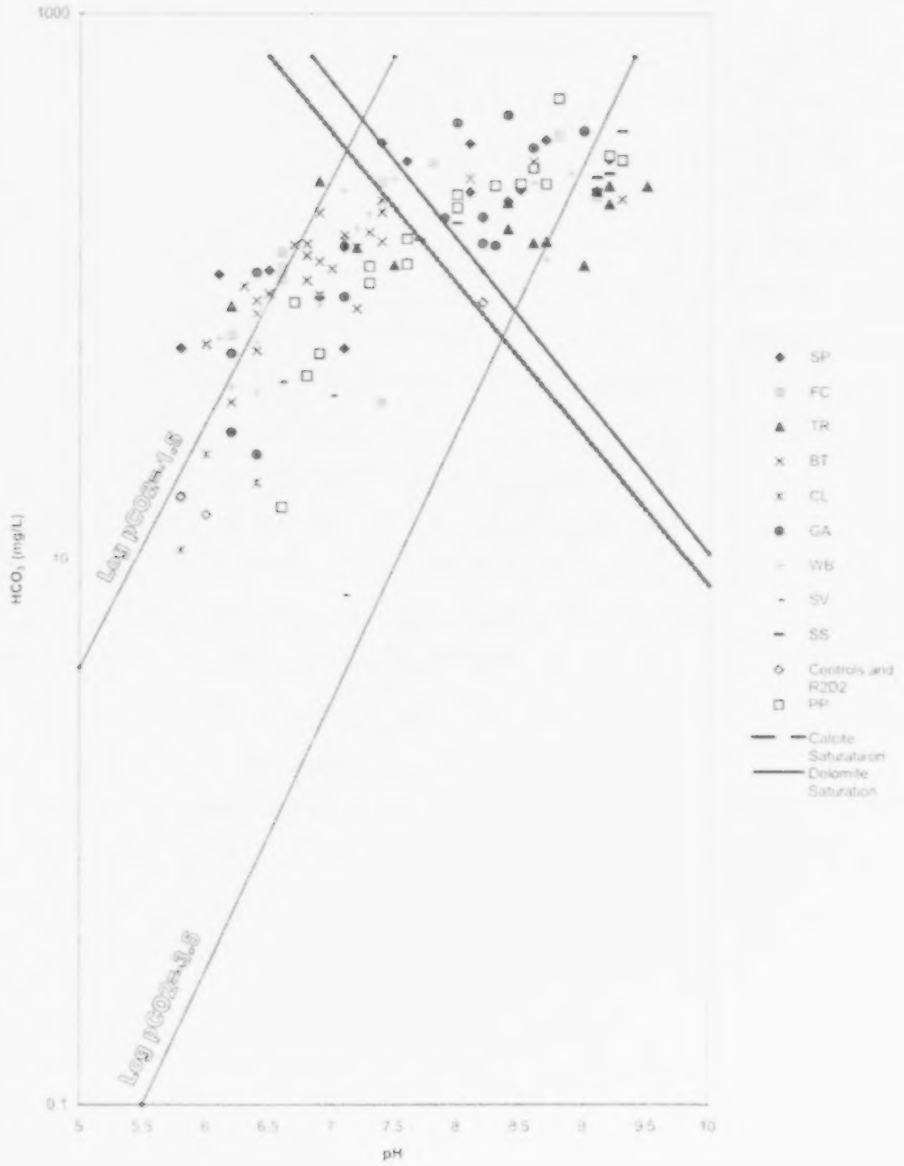

Figure 12. Dissolution of calcite and carbonate equilibia (all samples)

strongest signs of cation exchange. From a geologic point of view, increased reaction surface area could be accommodated by groundwater flow through pervasively fractured shale units.

Sample group BT is selected to illustrate the cation exchange process (Figure 11). This group of samples shows a distinctive trend (indicated by the arrow) whereby Na is enriched in the water and Ca is relatively depleted. The identification of cation exchange as a major process is also supported by the relationship between pH, HCO_3^- concentration and the cation molar ratio (CMR). CMR is the ratio between sum of (Na) and (K) and the sum of (Ca) and (Mg) (where brackets indicate molar concentrations). For the purpose of this study the molarity of K and Mg are quite low (Refer to Appendix A) and will be ignored in the calculation of the CMR.

CMR offers a method to differentiate between samples that have undergone various degrees of cation exchange. Table 6 lists the CMR ranges that were used to differentiate samples within the BT, WB and PP sample areas. These data are displayed in Figure 13.

Table 6. Generalized CMR ratios used to separate samples in Figure 13 (after Allen and Suchy, 2001)

CMR Range	Inferred Meaning
CMR>1	Cation exchange not active
1<CMR<3	Cation exchange
3<CMR<20	May indicate additional sources of Na^+
CMR>20	Significant additional sources of Na^+

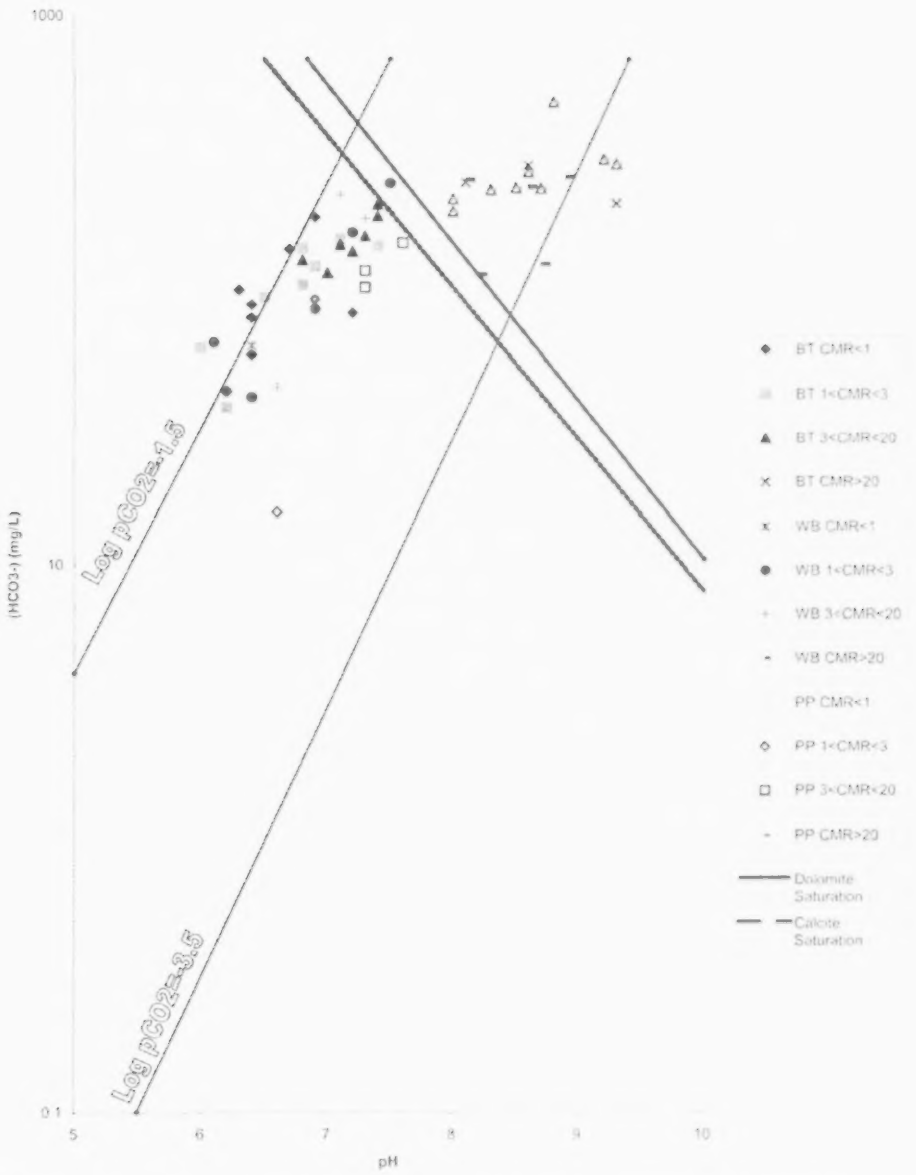

Figure 13. Cation molar ratio (CMR) and pH vs. HCO_3^- plot used to identify cation exchange and salinization for sample groups BT, WB and PP

Cation exchange is suggested by CMR values above 1. Within the range of 1 to 3, the gain of Na can be expected to be approximately balanced by the loss of Ca in the water. In other words, as quickly as calcite is dissolved, it is lost by cation exchange. At CMR values between 3 and 20, more Na is accumulating than can be explained by dissolution of calcite accompanied by cation exchange alone.

The relationship between the value of the CMR, cation exchange and calcite saturation is best understood by understanding how cation exchange affects the equilibrium of the calcite dissolution reaction:

$$CaCO_3\,(s) + H^+\,(aq) \Leftrightarrow Ca^{2+}\,(aq) + HCO_3^-\,(aq) \qquad (4.2)$$

Cation exchange involves the exchange of Ca^{2+} ions for Na^+ ions at negatively charged exchange sites on suitable exchange media (e.g., montmorillonite clays). Therefore Na^+ is added to the solution at the expense of Ca^{2+}. The removal of Ca^{2+} results in a shift to the right in Equation 4.2. This shift occurs in an attempt to reestablish the Ca^{2+} lost by cation exchange at the expense of calcite ($CaCO_3$). Dissolution continues as long as there is a source of calcite and H^+. The liberation of Na^+ and simultaneous removal of Ca^{2+} from solution generally results in an increase in the CMR, and an associated increase in HCO_3^- concentration and increase in pH, as cation exchange occurs. Because all waters with CMRs less than 3 fall below the calcite saturation line in Figure 13, we can conclude that cation exchange occurs both during dissolution of calcite and that calcite remains undersaturated. Similarly, those samples with a CMR greater than 3, but less than 20, plot below the calcite saturation line. This suggests that cation exchange also occurs in the absence of calcite dissolution (so the Na/Ca ratio increases because Ca is not replaced). All samples with a CMR above 20 plot above the calcite saturation line. This suggests that both Na and Ca have increased (Na more than Ca) and that the water is supersaturated with respect to calcite, or that the calcite saturation lines are not appropriately placed and should

shift to the right to accommodate a higher ionic strength solution. CMR values for BT are summarized in the following table (Table 7).

Table 7. Summary of cation molar ratios for sample group BT

	Sample Group BT	Relative Location on BT Piper Plot
CMR>1	1, 5, 12, 13, 15, 23, 27	Immature Groundwater Composition
1<CMR<3	2, 3, 11, 14, 16, 19, 20, 26	Intermediate Composition (partial cation-exchange)
3<CMR<20	6, 7, 8, 17, 21, 25	Intermediate-Evolved Composition (full cation-exchange)
CMR>20	9, 10, 18	Potential Salinization

4.1.3 Simple Mixing

The last major process discussed here that can influence the chemical evolution of groundwater is simple mixing, and particularly, its relevance to saltwater intrusion. Simple mixing involves combining two waters of different chemical, and sometimes, physical characters, without chemical reactions. The resulting composition is a hybrid of the two starting compositions. A common example of simple mixing involves the mixing of waters from different groundwater systems (e.g., shallow and deep). The net result is water with a new chemical composition that represents the different properties of the end member waters. Another example of simple mixing observed in coastal aquifers is salinization by active saltwater intrusion. During this process, saline groundwater, present at depth or intruded into the freshwater lens, mixes with fresh water. This process may be accelerated in certain areas by concentrated groundwater extraction from coastal aquifers.

4.2 General Evolution of Groundwater

In previous studies on Saturna Island, groundwater was generally observed to follow two linked evolutionary trajectories (Allen and Suchy, 2001): 1) cation-exchange (Na enrichment), followed by, 2) simple mixing with Cl-rich water (salinization) (Figure 14). Simple mixing of fresh groundwater (Ca-rich) and seawater (i.e., direct salinization without significant cation exchange) was observed locally (e.g., East Point, Saturna Island).

Groundwater chemical evolution on Hornby Island appears to follow similar trends, although of the waters sampled, none appear to represent direct salinization. Cation exchange followed by simple mixing appears to be the dominant evolutionary sequence on Hornby. Several sample groups appear to demonstrate strong cation exchange followed by salinization (SS, WB, TR, PP and SP) while others display strong cation exchange alone (e.g., BT and GA) (refer to Piper plots in Appendix B).

4.2.1 Saltwater Intrusion

Contamination by saltwater intrusion appears to be present locally on Hornby Island. Samples WB-3, WB-9, WB-10, SP-13 and TR-2 appear to have elevated EC, characteristic of advanced saltwater intrusion. This statement is based upon several lines of supporting evidence: 1) Na/Cl ratios, 2) Br/Cl ratios, 3) a Na-Cl bivariate plot and 4) a log EC vs. log CMR plot.

Firstly, Na/Cl ratios for WB-3, WB-9 and WB-10 are all very similar to that of the seawater sample C-2 (Table 8). The slightly higher ratios can be directly attributed to the fact that groundwater of intermediate composition (i.e., with a high concentration of Na gained from cation exchange) mixes with seawater. Thus, the final Na/Cl ratio is slightly higher than if fresh groundwater had mixed with seawater.

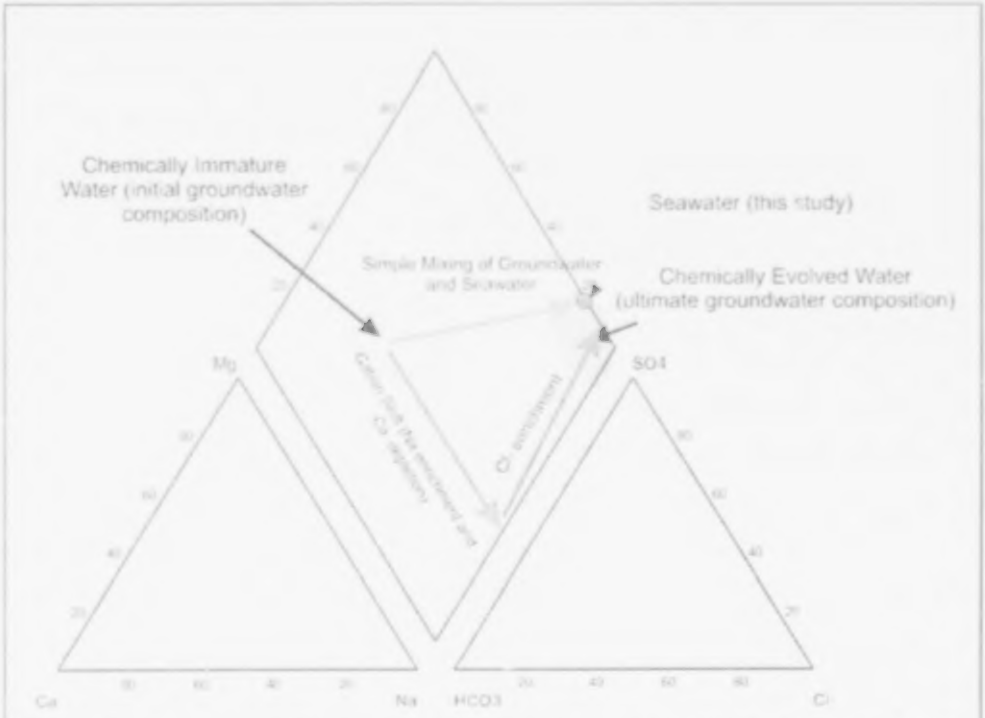

Figure 14. Representative groundwater evolutionary trajectories based on observations on Hornby and Saturna Islands.

Table 8. Summary of Na/Cl and Br/Cl ratios for samples indicating saltwater intrusion

Sample ID	Na/Cl	Br/Cl
WB-3	0.629	0.002
WB-9	0.75	0.004
WB-10	0.7	0.005
C-2 (Seawater Control)	0.559	0.004

Secondly, Br/Cl ratios also indicate potential saltwater intrusion. Groundwater on Hornby Island is characterized by Br concentrations below detection limits (<1.0 mg/L). However, WB-3, WB-9 and WB-10 have Br concentrations of 2.4, 1.5 and 3.6 mg/L, respectively. These Br concentrations are far below the 63 mg/L recorded for seawater (C-2) because the overall mixture is diluted. However, the ratios of Br/Cl are nearly the same (refer to Table 8), suggesting that relatively fresh groundwaters (with little or no dissolved Br) are mixing with seawater.

Thirdly, the Cl-Na bivariate plot (Figure 15) demonstrates a distinct strong correlation between Na and Cl concentrations for WB-3, WB-9 and WB-10.

The final line of evidence that suggests that the intrusion of seawater may be occurring in sample group WB is the independent relationship between log EC and the log CMR (Figure 16). High electrical conductivities are commonly associated with increased concentrations of the common anions Cl and SO_4^{2-}. If log EC is independent of log CMR the elevated CMR likely does not result from cation exchange. Rather, high CMRs probably the result of mixing of seawater and immature groundwater that has undergone little to no cation exchange. Saltwater intrusion does appear to be present in the Whaling Station Bay area and may be present in other areas. For example, samples TR-2 and SP-13 plot in similar positions on their respective Piper plots (Appendix B).

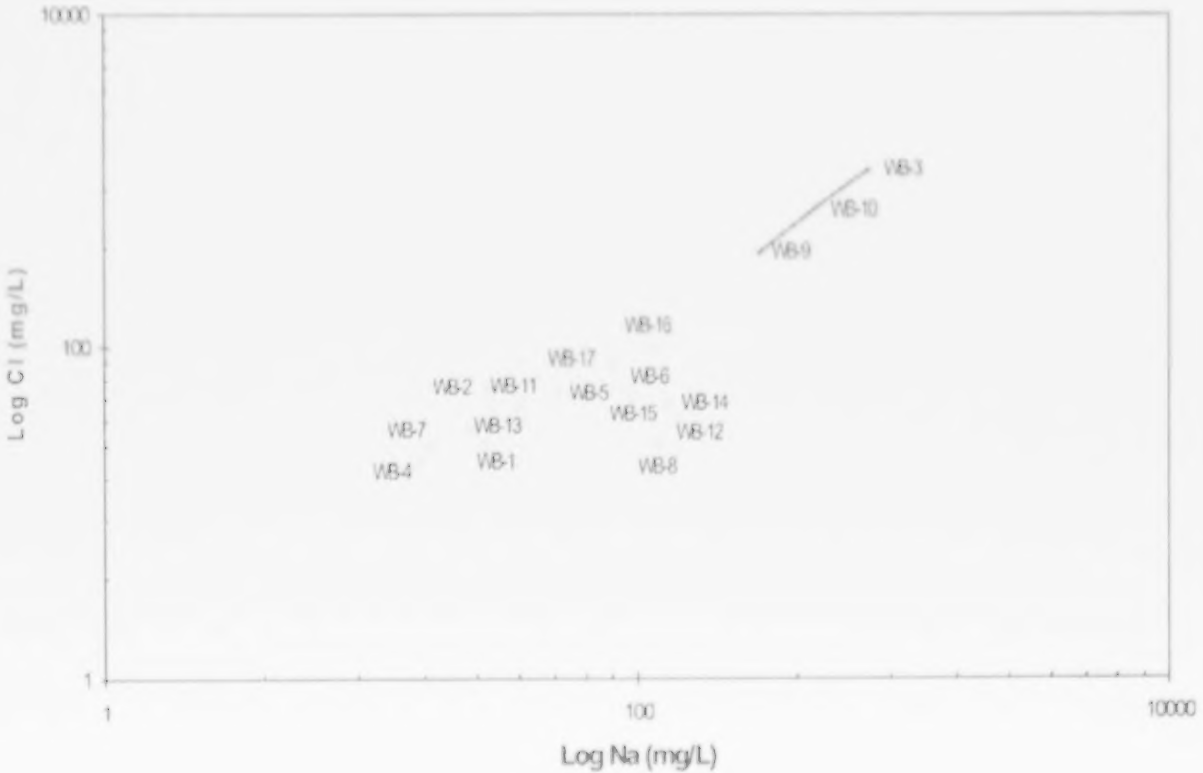

Figure 15. Cl-Na Bivariate plot for sample group WB indicating possible saltwater intrusion

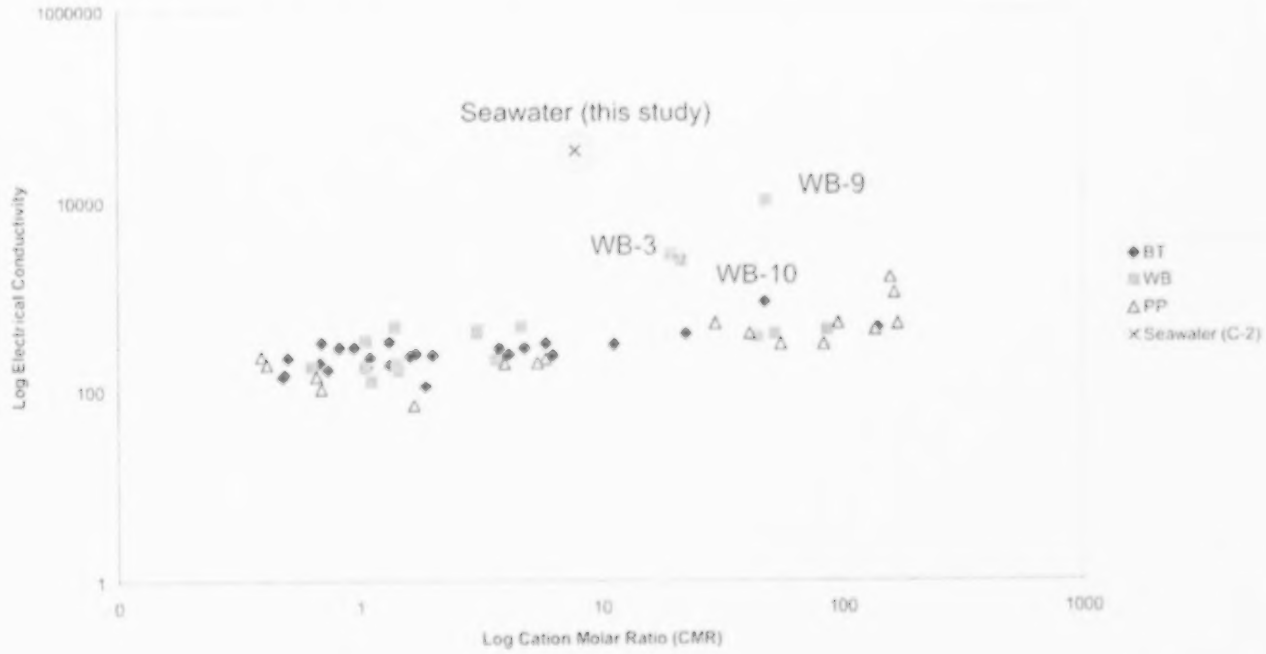

Figure 16. Log CMR vs. Log EC for sample groups BT, WB and PP

4.2.2 Origin of Dissolved Species

Specific sources of dissolved species, such as Na, Ca, Mg, Cl, Br and SO_4, would require a detailed examination of not only the geology (by undertaking whole rock geochemistry), but also the geological history of the region. It is beyond the scope of work for this project to identify all the potential sources of dissolved species. However, the composition of groundwater is primarily a function of the geological units through which it flows, the residence time, the presence of mudstone units, the proximity to the ocean, the geological history, and possibly the depth of wells.

Understanding the origin of dissolved species is a focus of ongoing study. It is speculated that the many wells tap into saline water at depth, and that this saline water is coincident with the current freshwater-saltwater interface beneath the island. Over the past 10,000 years or so, following glacial rebound of the Gulf Islands, seawater has been flushed out of the islands, and has been largely replaced by relatively fresh water, particularly at high elevation. Because seawater is present at depth beneath all islands it is difficult to say if this is remnant seawater or present day seawater. The dynamics of this system are not fully understood, but are be the focus of ongoing research that will aim to model the rebound of the Gulf Islands and determine the equilibrium position of the freshwater-saltwater interface.

Regardless of the age of the saline water at depth, the chemistry of the groundwater for a large proportion of the wells indicates mixing with seawater. Furthermore, the observed distribution of dissolved constituents in groundwater, such as manganese, fluoride and boron, may be linked to the complex geological history of rebound, and may in fact, be associated with old seawater incursion.

4.3 The Groundwater Flow Regime

4.3.1 Groundwater Flow Regions

Chwokja (1984) defined seven groundwater regions largely on the basis of topography (Figure 6). These roughly equate to the sample groups in the following manner:

- Region 1 – SS (Shingle Spit)
- Region 2 – PP (Phipps Point)
- Region 3 – GA (Galleon Beach)
- Region 4 – WB (Whaling Station Bay)
- Region 5 – BT and TR (Big Tree and Tribune Bay)
- Region 6 – CL, SV and SP (Crown Land Parcel, Strachan Valley and Sand Piper Beach)
- Region 7 – FC (Ford Cove)

For the most part, there is relatively good agreement between the groundwater regions determined on the basis of topography and those identified on the basis of the chemical evolution of groundwater identified within each flow region. That is, groundwater appears to evolve chemically from the higher elevation areas within each flow region to areas of lower elevation. In this respect, it is entirely appropriate to subdivide the island into groundwater flow regions on the basis of surface topography. But, it is important to recognize that some flow regions show similar chemical evolution, suggesting that they are continuous in the subsurface. For example, sample groups GA and BT lie within Regions 3 and 5, respectively. On the basis of topography these regions appear to be isolated. But, the similar chemical evolution of groundwater sampled in each area suggests continuity between these 2 regions. The nature of the continuity can be anticipated to correspond with subsurface flow along bedding contacts, extensive fractured mudstone horizons and/or fracture-fault zones.

4.3.2 Recharge and Discharge Areas

Identifying groundwater recharge zones has strong implications in decisions regarding land use planning. Residential, agricultural and forestry development within the headwaters of surface flow regions (watersheds) can potentially result in the degradation of both surface and groundwater quality and quantity.

Recharge and discharge areas represent zones of water input and output for groundwater systems. Compositionally, groundwater in recharge zones will be immature while discharge zones will generally be more evolved. Areas in between recharge and discharge areas will generally have intermediate compositions. This type of pattern is observed on Hornby Island.

As well, the concentration of dissolved constituents can generally be linked to the flow paths (except perhaps for anomalous concentrations). The concentration contours shown in the maps for each dissolved constituent (Appendix C) generally outline the recharge areas (i.e., low concentrations are typically measured in these areas).

Working within this framework, the potential recharge and discharge areas were delineated for Hornby Island (Figure 17). The outline of the two recharge areas (one large one over the main part of the island and a small on the peninsula by Whaling Station Bay) is rather extensive. This indicates that recharge occurs over a broad area and is not confined to the areas of high elevation (such as Mt. Geoffrey). The Crown Land parcel constitutes a large portion of the recharge area for Hornby, but areas along the base of these high elevation areas also act as recharge areas.

It is important to recognize that rock type and the intensity of fracturing will play a role in determining if recharge occurs or does not occur at a local scale. Geological units that have very low porosity and have a low density of fractures

Figure 17. Potential local groundwater recharge zones defined on the basis of groundwater geochemistry

likely will not support large amounts of recharge, although one large fracture can potentially offer a significant pathway for recharge. In contrast, mudstone units (such as the Northumberland Formation) and/or densely fractured sandstones offer ideal recharge areas.

Notwithstanding geological complexity, the overall movement of groundwater on the island is from high to low elevation. This conclusion is based not only on the groundwater chemistry results, but also the drilling data for the island, which confirm that static water levels are higher at high elevation. Recharge from any other area (such as Vancouver Island) would require not only an upward hydraulic gradient so that deep wells would have higher static water levels than shallow wells both in the inland areas and along the coast, but also that there be no evidence of immature groundwater compositions nor an evolution of water chemistry that was continuous and complete on the island.

4.3.3 Geology as a Control on Groundwater Geochemistry

Aquifers on the Gulf Islands are characterized as fractured sedimentary bedrock aquifers. The low porosity of the sandstone and conglomerate units hint at a strong dependence on fracturing. This means that groundwater is much more likely to flow through fractures rather that through the porous matrix. This is not to say that there is no flow through unfractured bedrock, rather the majority of flow is accommodated by discrete flow paths.

The relative high permeability (due to high fracture intensity and interconnectivity) of mudstone units may cause groundwater to flow preferentially within these units. This conclusion is supported by Gulf Island water well drillers who generally find that principle water bearing units are at mudstone horizons. The prevalence of a cation exchange process in most waters sampled in this study and on Saturna Island suggests that groundwater does move through units that contain significant amounts of clay. The widespread occurrence of cation

exchange also hints that clay units are widespread, and are not necessarily restricted to mudstone-dominant formations (this is supported by the observation that many sandstone formations have mudstone horizons). Cation exchange was observed to be absent in predominantly sandstone formations (e.g., the De Courcy Formation on Saturna) (Allen and Suchy, 2001).

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- Groundwater on Hornby Island is recharged locally, typically at high elevation in areas corresponding to Mount Geoffrey and the Crown Land. However, the relatively immature chemical composition of many well waters (calcium-bicarbonate type water) situated at lower elevations suggests that recharge occurs over a significant portion of the island.
- Groundwater regions, originally defined on the basis of topography, appear to coincide with chemical evolution trends identified in the sample groups employed for this study. However, due to the limited amount of structural data available for Hornby Island, and a corresponding lack of subsurface lithological control, there are some areas where topographic divides may be bypassed by subsurface inhomogeneities like discontinuous fractured mudstone stringers and non-systematic fractures.
- Chemical evolution of groundwater on Hornby Island demonstrated cation exchange and salinization as dominant evolutionary pathways. This is in general agreement with the observations and results from Saturna Island.
- Cation exchange (Ca exchanging for Na) is identified as a dominant geochemical process during the evolution of groundwater. In general, cation exchange was observed to be most prevalent in areas underlain by fine-grained sedimentary rocks. Therefore, it is suggested that groundwater flow through mudstone units may be the cause for the high occurrence of cation exchange. However, there was variability in this trend when sample groups containing different fine-grained formations were compared. This may suggest that cation exchange is dependent on the lithology encountered. Not all fine-grained units have the same ability to support cation exchange.

- Mature groundwaters, characterized by higher concentrations of chloride, result from mixing between the Na-rich groundwater and saline groundwater at depth, associated with either modern seawater or remnant seawater. Several wells in the Whaling Station Bay area show significant salinization, and suggest that saltwater intrusion may be prevalent in that area.

5.2 Recommendations

- Continue to collect and reevaluate groundwater geochemical data as a means of tracking potential trends in water quality. Observation of long-term patterns in groundwater geochemistry may allow for better understanding of the processes causing the changes. This type of exercise may be particularly useful for areas like Whaling Station Bay.
- Additional sampling of wells not sampled in this study may provide a higher resolution, and an improved database, for future studies.
- Groundwater quality and quantity are of paramount importance to residents on Hornby Island and the other Gulf Islands. As such, water conservation, proper waste disposal and placement of human development should be made a priority in future land use planning. This should be done so as to protect sensitive groundwater recharge areas in upland locations.
- For future wells drilled on the Gulf Islands the collection of detailed drill logs may allow for the collection of otherwise unobtainable subsurface geological controls on groundwater flow and evolution.
- The collection of whole rock geochemical analysis of samples of the fine-grained units (Northumberland and Spray Formations) and from fine-grained interbeds within the Geoffrey Formation may allow for the quantification of the differing cation exchange capacities of the different mud rich units underlying Hornby Island. Without this and other geologic data (e.g., structural data) a clear understanding of

subsurface groundwater flow and evolution will be made extremely difficult.

- Conduct detailed surficial mapping for Hornby Island so as to be able to delineate the spatial distribution of permeable surficial sediments, and eventually incorporate this information into the hydrogeological model for this island.

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APPENDIX A

HYDROGEOCHEMICAL SUMMARY TABLE OF DATA COLLECTED FOR THIS STUDY

		Units	MDL	Sample ID			
				SP-1	SP-2	SP-3	SP-4
Physical Parameters	Depth (m) or Location	m	---	81	5	Surface	55
	pH (Lab)	pH units	0.1	8.1	7.1	7.3	9.1
	pH (Field)	pH units	0.1	8.1	6.9	7.1	9.2
	Total Carbonate Alkalinity as HCO_3 (Field)	mg/L		345	93	61	345
	Conductivity	µS/cm	---	1605	213	167	619
	Calculated Total Hardness (Lab)	mg/L		11.1	86.9	51.2	2.1
	Water Temperature (Field)	°C	0.1	12.0	12.8	16.8	11.7
	Log pCO_2 (Calculated)*	Bar		-2.719	-2.054	-2.419	-3.861
ANIONS	HCO_3 (Calculated)*	mg/L	---	336.1	91.47	59.54	293.6
	Cl	mg/L	1	460	28	32	66
	F	mg/L	0.1	5.32	< 0.10	< 0.10	3.06
	I	mg/L	1	---	---	---	---
	Br	mg/L	1	< 1.0	< 1.0	< 1.0	< 1.0
	Nitrate Nitrogen Dissolved (N)	mg/L	---	---	---	---	---
	Nitrate+Nitrite (N)	mg/L	0.02	---	---	---	---
	Nitrite Nitrogen (N)	mg/L	0.005	---	---	---	---
	SO_4	mg/L	1	4.2	4.1	3	16.2
Dissolved Metals (Cations)	Al	mg/L	0.02	< 0.02	0.07	0.13	< 0.02
	Sb	mg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05
	As	mg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05
	Ba	mg/L	0.001	0.062	0.016	0.007	0.01
	Be	mg/L	0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
	Bi	mg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05
	B	mg/L	0.008	2.8	0.037	0.051	2
	Cd	mg/L	0.002	< 0.002	< 0.002	< 0.002	< 0.002
	Ca	mg/L	0.05	3.89	28	11	0.7
	Cr	mg/L	0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Co	mg/L	0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Cu	mg/L	0.005	< 0.005	0.127	0.012	< 0.005
	Fe	mg/L	0.005	0.017	0.113	0.255	0.006
	Pb	mg/L	0.03	< 0.03	< 0.03	< 0.03	< 0.03
	Mg	mg/L	0.05	0.34	4.13	5.77	0.09
	Mn	mg/L	0.001	0.005	0.009	0.088	0.001
	Mo	mg/L	0.005	< 0.005	< 0.005	< 0.005	< 0.005
	Ni	mg/L	0.008	< 0.008	< 0.008	< 0.008	< 0.008
	P (as Orthophosphate)	mg/L	0.1	0.4	< 0.1	< 0.1	0.1
	K	mg/L	1	< 1	3	2	< 1
	Se	mg/L	0.03	< 0.03	< 0.03	< 0.03	< 0.03
	Ag	mg/L	0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Na	mg/L	0.05	465	20.8	25.1	199
	Sr	mg/L	0.001	0.281	0.097	0.062	0.043

S	mg/L	0.1	3.1	3.2	2.4	36.8
Te	mg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	mg/L	0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	mg/L	0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	mg/L	0.003	< 0.003	< 0.003	0.004	< 0.003
V	mg/L	0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	mg/L	0.005	< 0.005	0.035	< 0.005	< 0.005
Zr	mg/L	0.005	< 0.005	< 0.005	< 0.005	< 0.005

* Calculated using SOLMINEQ

	SP-5	SP-6	SP-7	SP-8	SP-9	SP-10	SP-11	SP-12	SP-13	SP-14
Depth (m) or Location	11	37	57	18	61	37	34	91	91	17
pH (Lab)	7.3	6.2	8.1	6.6	8	8.3	8.3	8.2	7	8
pH (Field)	7.1	5.8	7.6	6.1	7.4	8.7	8.4	8.5	6.5	8.1
T Alk HCO_3 (Field)	140	60	292	112	342	367	215	237	126	226
Cond.	245	170	448	240	649	985	551	636	1382	319
T Hard. (Lab)	35	35.8	4.5	91.1	73.9	5.7	53.7	56.4	1140	4.7
Temp. (Field)	13.4	14.0	13.1	12.3	12.3	10.8	12.9	10.8	10.2	11.5
Log pCO_2 (Calculated)*	-2.072	-1.132	-2.263	-0.761	-2.005	-3.301	-3.313	-3.273	-1.648	-2.871
HCO_3^- (Calculated)*	139.4	59.59	289.1	110.8	337.7	345.7	205.6	226.2	114.5	222.5
Cl^-	28	33	29	25	79	210	120	150	6600	21
F^-	0.19	< 0.10	0.48	< 0.10	0.39	1.91	0.5	0.53	3.63	0.19
I^-	---	---	---	---	---	---	---	---	< 1	---
Br	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	17	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	---	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	---	---	---	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	---	---	---	---	---	---	---	---	---	---
SO_4^{--}	6.4	5.7	18.5	15.1	53.5	23.8	5.2	3.3	< 1.0	8.9
Al	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.042	0.019	0.009	0.024	0.04	0.017	0.075	0.083	5.45	0.022
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.169	0.033	0.398	0.052	0.418	1.46	0.396	0.455	2.89	0.236
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	9.79	5.78	1.34	24.5	23	1.93	13.9	13.2	378	1.5
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	0.019	< 0.005	0.278	0.012	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Fe	1.16	0.036	0.027	0.008	0.005	0.006	< 0.005	0.007	14.6	0.123
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	2.56	5.18	0.29	7.27	4	0.21	4.61	5.69	48	0.22
Mn	0.255	0.007	0.005	0.028	0.062	0.004	0.019	0.01	0.608	0.005
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	0.2	< 0.1	0.4	< 0.1	0.1	0.3	0.1	0.2	4.5	0.1
K	< 1	< 1	< 1	1	1	< 1	1	3	9	< 1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	61.8	32.2	146	34.4	177	297	139	157	3700	108
Sr	0.135	0.072	0.064	0.177	0.44	0.119	0.274	0.44	36.2	0.129
S	5.5	4.1	10.4	8.1	22.8	48.8	16.5	16.8	0.5	10.4

Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	0.008	0.044	< 0.005	0.026	< 0.005	< 0.005	< 0.005	< 0.005	0.062	< 0.005
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	FC-1	FC-2	FC-3	FC-4	FC-5	FC-6	FC-7	FC-8	FC-9	TR-1
Depth (m) of Location	46	76	107	91	Dug (5 m)	Dug (4 m)	15		76	15
pH (Lab)	8	9.3	8.2	7.7	7	6.7	7.4	7.2	8.9	8
pH (Field)	7.4	9.1	7.8	7.4	6.6	6.2	6.6	6.6	8.8	8.7
T Alk HCO_3^-(Field)	246	242	290	38	107	67	135	118	387	154
Cond.	514	400	486	122	210	150	424	306	525	260
T Hard. (Lab)	170	5.5	11.7	44	98.1	56.9	165	106	14.2	0.7
Temp. (Field)	10.4	13.4	10.8	10.2	11.9	12.3	12.8	13.9	12.9	14.6
Log pCO_2 (Calculated)*	-2.150	-3.890	-1.882	-2.939	-1.692	-1.489	-1.601	-1.650	-3.366	-3.653
HCO_3^- (Calculated)*	241.9	213.5	286.9	37.58	106.5	66.78	133.7	117.3	359.5	146.7
Cl^-	33	30	20	27	32	25	67	46	27	38
F^-	< 0.10	0.72	1.23	< 0.10	< 0.10	< 0.10	0.11	0.1	3.49	0.5
I^-	< 1	---	---	---	---	---	---	---	---	---
Br^-	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	---	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	---	---	---	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	---	---	---	---	---	---	---	---	---	---
SO_4^-	83	37.5	35.8	3.4	4.7	2.8	33.2	21.2	13.3	1.1
Al	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.02	< 0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.081	0.02	0.016	0.007	0.013	0.007	0.1	0.03	0.013	0.002
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.121	0.413	1.06	0.009	0.018	0.012	0.049	0.028	2.06	0.454
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	48	1.66	3.85	10.9	29.7	16.3	47.3	29	3.74	0.2
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	0.007	0.065	< 0.005	0.037	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Fe	0.008	< 0.005	0.008	< 0.005	< 0.005	0.706	1.27	0.04	0.01	< 0.005
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	12.1	0.32	0.5	4.07	5.81	3.93	11.5	8.22	1.19	0.06
Mn	0.011	< 0.001	0.004	0.012	0.008	0.066	0.267	0.016	0.012	< 0.001
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
K	2	< 1	< 1	< 1	< 1	1	1	2	< 1	< 1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	86.4	130	151	15.1	20	16	48.3	34	163	78.8
Sr	1.12	0.056	0.106	0.063	0.158	0.06	0.317	0.164	0.068	0.012

S	32	16.7	16.5	2.6	3.5	2.2	15	10.9	7.3	9.8
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	< 0.005	< 0.005	0.107	0.098	0.022	0.019	< 0.005	0.192	< 0.005	< 0.005
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	TR-2	TR-3	TR-4	TR-5	TR-6	TR-7	TR-8	TR-9	TR-10	TR-11
Depth (m) or Location	Well	Well	Well	46	19	Well	Well	23	Well	29
pH (Lab)	8	7.9	9.1	7.9	6.9	8.9	9.5	9.1	8.9	8.2
pH (Field)	8.4	7.6	9	7.5	6.2	9.1	9.5	9.2	9.2	8.4
T Alk HCO_3 (Field)	173	123	132	121	85	255	319	233	277	209
Cond.	1642	219	268	179	184	414	727	459	575	354
T Hard. (Lab)	91.7	< 0.7	< 0.5	21.3	91.7	1.5	2.2	< 1.1	3.1	15.8
Temp. (Field)	10.9	14.5	10.9	12.4	12.2	12.1	14.5	11.6	12.3	13.0
Log pCO_2 (Calculated)*	-3.330	-2.628	-4.030	-2.535	-1.390	-2.866	-4.247	-4.020	-3.951	-3.218
HCO_3 (Calculated)*	163.6	122.4	119.6	120	84.79	225.1	233.9	200.9	234.4	203.1
Cl^-	580	17	30	17	20	47	130	81	100	37
F^-	0.5	0.27	0.54	0.21	< 0.10	1.59	1.9	1.11	1.78	0.63
I^-	---	---	---	---	< 1	---	< 1	---	---	---
Br	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	---	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	---	---	---	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	---	---	---	---	---	---	---	---	---	---
SO_4	4.6	6.2	2	3.6	4.7	< 1.0	< 1.0	1.3	< 1.0	4.3
Al	< 0.02	< 0.02	0.03	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.02	< 0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.495	0.004	0.002	0.03	0.007	0.005	0.009	0.005	0.01	0.017
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.581	0.257	0.451	0.167	0.016	1.27	1.67	0.925	1.72	0.727
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	30.8	0.21	0.1	5.81	28.7	0.46	0.7	0.35	0.97	4.4
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	0.005	< 0.005	0.147	0.012	< 0.005	< 0.005	< 0.005	< 0.005	0.005
Fe	0.044	0.006	0.022	< 0.005	< 0.005	0.016	0.007	< 0.005	0.019	0.015
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	3.6	< 0.05	< 0.05	1.66	4.87	0.09	0.1	< 0.05	0.17	1.17
Mn	0.098	0.002	0.001	0.001	0.002	0.003	< 0.001	< 0.001	0.003	0.005
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	0.5	0.2	0.3	0.1	< 0.1	0.2	0.2	0.1	0.2	< 0.1
K	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	422	63.9	80.6	45.5	14.8	124	198	140	163	103
Sr	2.58	0.015	0.006	0.2	0.13	0.025	0.047	0.026	0.073	0.11

S	4.6	4.3	7.7	2.8	3.4	1	6.1	10.9	4.9	3.4
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	< 0.005	0.005	< 0.005	0.035	0.02	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	TR-12	TR-13	TR-14	BT-1	BT-2	BT-3	BT-4	BT-5	BT-6	BT-7
Depth (m) or Location	Dug (5 m)	46	Well	14	21	Dug (6 m)	Dug (4 m)	29	30	30
pH (Lab)	7.5	8.6	7.7	7.9	7.6	7	7.9	7.3	7.9	8.1
pH (Field)	6.9	8.6	7.2	7.2	6.8	7.1	6.4	6.9	7.2	7.4
T Alk HCO_3 (Field)	244	158	140	84	145	156	55	94	140	209
Cond.	364	332	354	292	248	225	143	200	232	324
T Hard. (Lab)	36.8	31.8	36.1	123	70.9	47.2	123	81.3	38.5	40
Temp. (Field)	11.8	13.2	13.5	12.7	10.8	13.7	11.8	13.8	11.7	12.1
Log pCO_2 (Calculated)*	-1.638	-3.375	-2.172	-2.396	-1.761	-2.027	-1.779	-2.036	-2.173	-2.205
HCO_3^- (Calculated)*	242.8	144.6	139.4	83.07	143.6	155.1	58.57	93.2	139.5	207.1
Cl^-	39	46	64	26	25	25	9.2	26	22	28
F^-	< 0.10	0.31	0.42	0.3	0.32	< 0.10	0.3	< 0.10	0.24	0.33
I^-	---	---	---	---	---	---	---	---	---	---
Br^-	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	0.14	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	---	---	0.14	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	---	---	0.005	---	---	---	---	---	---	---
SO_4	1.1	4.7	2.3	4.6	4.2	3.1	4.7	5.4	1.3	4.4
Al	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.03	0.05	< 0.02	< 0.02	< 0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.035	0.014	0.015	0.066	0.043	0.007	0.009	0.013	0.024	0.025
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.1785	0.014	0.397	0.217	0.4	0.054	< 0.008	0.058	0.302	0.568
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	8.795	54.5	9.56	33	21.2	12.2	37.1	23.8	11	10.2
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	< 0.005	0.078	0.022	< 0.005	< 0.005	< 0.005	0.101	< 0.005	< 0.005
Fe	0.018	0.496	0.019	< 0.005	0.164	0.368	0.195	0.03	0.107	0.026
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	3.22	10.5	2.97	9.84	4.36	4.07	7.42	5.32	2.69	3.52
Mn	0.0415	1.05	0.033	0.039	0.176	0.02	0.18	0.045	0.092	0.062
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	0.023	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
K	< 1	1	< 1	2	1	1	< 1	1	1	2
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	75.25	30.3	84.9	35.2	43.7	18	21.4	19.9	51.3	81.4
Sr	0.25	0.297	0.198	0.614	0.375	0.05	0.15	0.134	0.246	0.271

S	3.75	1	1.8	3.3	3.8	2.3	5.4	3.6	2.7	3.1
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	< 0.005	< 0.005	0.029	0.031	< 0.005	0.014	0.419	0.031	< 0.005	0.011
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	BT-8	BT-9	BT-10	BT-11	BT-12	BT-13	BT-14	BT-15	BT-16	BT-17
Depth (m) or Location	61	30	27	46	6	37	Well	Well	34	Well
pH (Lab)	7.9	8.2	8.2	7.1	7.5	7	7.5	7.3	6.8	7.6
pH (Field)	7.4	8.6	8.1	6.5	6.7	6.3	6.8	6.4	6.2	7
T Alk HCO_3 (Field)	190	307	255	95	144	101	106	81	38	117
Cond.	316	869	405	183	228	152	234	331	113	246
T Hard. (Lab)	20.8	13.1	13.7	66.4	110	73.7	66.8	129	28.1	36.2
Temp. (Field)	11.5	10.4	10.6	9.5	10.0	10.5	11.0	12.6	14.7	11.9
Log pCO_2 (Calculated)*	-2.241	-3.267	-2.819	-1.637	-1.667	-1.412	-1.895	-1.621	-1.734	-2.052
HCO_3^- (Calculated)*	188.3	288.7	249.7	94.37	142.4	100.5	105.4	79.7	37.74	116.6
Cl	35	200	32	24	20	13	32	80	24	32
F	0.8	2.79	0.59	0.11	< 0.10	< 0.10	0.24	< 0.10	< 0.10	0.15
I	---	---	---	---	---	---	---	---	< 1	---
Br	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	1.5	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	---	---	---	---	---	0.3	---	0.17
Nitrate+Nitrite (N)	---	---	---	---	---	---	---	0.3	---	0.17
Nitrite Nitrogen (N)	---	---	---	---	---	---	---	< 0.005	---	< 0.005
SO_4	1.9	< 1.0	3.3	4.2	3.2	5	6.1	8.5	2.8	7.2
Al	< 0.02	< 0.02	0.08	0.04	0.04	0.04	< 0.02	< 0.02	< 0.02	< 0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.01	0.024	0.014	0.016	0.009	0.037	0.039	0.045	0.005	0.025
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.981	2.6	0.651	0.054	0.014	0.032	0.227	0.037	0.047	0.234
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	5.83	4.09	4.45	17.8	33.3	22.8	17.7	39.6	6.07	10.4
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	< 0.005	< 0.005	0.032	< 0.005	0.009	< 0.005	0.097	0.016	0.01
Fe	0.146	0.016	0.06	0.095	0.7	0.03	0.718	0.306	0.014	0.021
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	1.51	0.69	0.62	5.33	6.57	4.06	5.49	7.26	3.15	2.48
Mn	0.056	0.042	0.027	0.199	0.293	0.003	0.1	0.03	< 0.001	0.018
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	0.2	0.2	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
K	< 1	1	1	< 1	2	< 1	1	1	< 1	2
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	83.6	232	115	24.9	20.1	13.1	37.5	32.5	17.3	53.4
Sr	0.256	0.255	0.184	0.138	0.111	0.214	0.203	0.482	0.055	0.254

S	1.8	0.2	4.1	2.9	2.3	3.5	4.1	4.9	2	4.4
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	0.041	0.005	< 0.005	0.019	0.01	0.008	< 0.005	0.04	0.012	0.007
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	BT-18	BT-19	BT-20	BT-21	BT-23	BT-24	BT-25	BT-26	BT-27	CL-1
Depth (m) or Location	Well	Well	35	64	Well	30	27	Well	Well	Surface
pH (Lab)	9.2	8	7.5	8	7.3	8	7.7	6.8	7.9	7.1
pH (Field)	9.3	7.4	6.9	7.3	6.4	6.8	7.1	6	6.9	6
T Alk HCO_3 (Field)	251	149	124	160	90	131	149	62	189	24
Cond.	464	334	241	285	168	242	280	191	290	67.7
T Hard. (Lab)	2.5	107	63.4	41.1	80.1	27.2	47.8	58.5	113	21.2
Temp. (Field)	10.5	12.8	14.3	11.5	13.3	11.1	14.3	13.8	15.1	13.7
Log pCO_2 (Calculated)*	-4.105	-2.364	-1.928	-2.221	-1.563	-1.802	-2.041	-1.321	-1.770	-1.717
HCO_3^- (Calculated)*	209.5	146.6	123.6	158.8	89.05	130	147.8	61.93	186.4	24.26
Cl^-	24	46	25	24	19	25	27	39	25	15
F^-	0.63	0.1	0.15	0.36	0.1	0.18	0.28	< 0.10	0.23	< 0.10
I^-	---	---	---	---	---	---	---	---	---	---
Br^-	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Nitrate Nitrogen Dissolved (N)	0.06	---	---	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	0.06	---	---	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	< 0.005	---	---	---	---	---	---	---	---	---
$SO_4^{=}$	48.6	13.6	8.9	12.4	4.7	8.7	12.4	7.3	11	1.5
Al	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.04
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.006	0.069	0.061	0.031	0.021	0.034	0.043	0.018	0.06	0.006
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.865	0.225	0.192	0.589	0.049	0.374	0.463	0.095	0.264	< 0.008
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	0.82	29.2	19.1	11.7	20.3	7.14	13.8	14.1	34	5.23
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	< 0.005	< 0.005	< 0.005	0.479	0.026	< 0.005	0.373	< 0.005	0.006
Fe	< 0.005	0.023	0.008	0.046	< 0.005	0.359	0.034	0.245	4.38	0.073
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	0.12	8.28	3.82	2.89	7.14	2.28	3.25	5.66	6.71	1.98
Mn	< 0.001	0.113	0.052	0.049	0.006	0.061	0.034	0.043	0.283	0.014
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
K	< 1	3	< 1	2	< 1	2	1	1	1	1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	133	49.6	46	70.4	20.3	59.5	64.8	26.3	38.4	9.73
Sr	0.04	0.72	0.333	0.386	0.187	0.242	0.301	0.129	0.475	0.037
S	20.2	6.9	5.1	6.7	3.3	5.2	6.5	4.2	5.7	1.4

Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	< 0.005	< 0.005	0.013	< 0.005	0.019	0.015	0.019	0.066	0.433	0.009
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	CL-2	CL-3	CL-4	GA-1	GA-2	GA-3	GA-4	GA-5	GA-6	GA-7
Depth (m) or Location	Surface	Surface	Surface	Well	66	Well	67	Well	Well	Well
pH (Lab)	6.9	6.8	7.3	8.3	8.7	6.8	8.4	8.5	7.3	8.5
pH (Field)	5.8	5.8	6.4	7.9	9	6.2	8.4	8	6.4	8.6
T Alk HCO_3^- (Field)	17	11	20	182	417	57	442	405	113	343
Cond.	86	83.8	82.8	278	616	142	724	516	173	435
T Hard. (Lab)	31.4	24.8	26.2	16.6	5.4	47.6	6.4	31.6	68.1	54.2
Temp. (Field)	11.7	12.6	13.9	17.2	14.7	13.8	11.2	12.2	12.0	12.4
Log pCO_2 (Calculated)*	-1.673	-1.854	-2.212	-2.762	-3.553	-1.554	-2.895	-1.463	-3.218	-2.151
HCO_3^- (Calculated)*	17.03	10.86	19.17	178.9	372.7	57.11	426.1	398.3	112.7	323.9
Cl^-	15	18	15	29	49	17	88	34	14	28
F^-	< 0.10	< 0.10	< 0.10	1.66	5.71	0.12	6.02	2.53	< 0.10	1.5
I^-	---	---	---	---	< 1	---	< 1	---	---	---
Br^-	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	---	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	---	---	---	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	---	---	---	---	---	---	---	---	---	---
SO_4	4.3	2.9	3.6	1.2	7	5.9	< 1.0	1.9	3.9	3.1
Al	0.03	0.06	0.07	0.07	< 0.02	< 0.02	< 0.02	< 0.02	0.03	< 0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.008	0.006	0.006	0.007	0.016	0.019	0.015	0.041	0.021	0.037
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	< 0.008	< 0.008	0.016	1.38	2.28	0.046	3.86	1.41	0.094	0.777
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	7.3	5.51	6.61	5.01	1.15	12.4	2.06	6.36	20.6	15.4
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	< 0.005	< 0.005	0.005	< 0.005	0.744	0.008	0.009	0.008	< 0.005
Fe	< 0.005	0.085	0.036	0.071	< 0.005	0.11	0.015	< 0.005	0.01	0.005
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	3.19	2.69	2.35	1	0.62	4.05	0.31	3.82	4.05	3.83
Mn	0.002	0.104	0.005	0.014	0.001	0.36	0.011	0.002	0.008	0.001
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.2	< 0.1	< 0.1	< 0.1
K	< 1	< 1	< 1	< 1	1	< 1	< 1	1	< 1	1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	11.3	11	11	82.8	190	16.1	230	161	22.7	126
Sr	0.06	0.042	0.041	0.047	0.063	0.078	0.099	0.22	0.136	0.276

S	2.9	2	2.5	0.9	4.4	3.9	0.6	1.5	3	7.2
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	< 0.005	< 0.005	< 0.005	0.046	< 0.005	0.177	< 0.005	0.015	0.025	< 0.005
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	GA-8	GA-9	GA-10	GA-11	GA-12	GA-13	WB-1	WB-2	WB-3	WB-4
Depth (m) or Location	Well	Dug (2 m)	18	Well	39	15	Dug (4 m)	Surface	91	Dug
pH (Lab)	8.4	6.9	8.5	6.8	8.4	7.7	7.2	7.4	7.6	6.8
pH (Field)	8.2	6.4	8.2	6.2	8.3	7.1	6.1	6.4	6.9	6.4
T Alk HCO_3 (Field)	148	24	185	29	146	93	65	41	95	63
Cond.	250	91	247	78	224	182	179	195	2830	182
T Hard. (Lab)	6.9	28.8	67	23.9	68	78.5	65.8	58.5	99	66.4
Temp. (Field)	11.9	11.8	11.6	9.7	10.6	10.6		12.8	12.3	16.5
Log pCO_2 (Calculated)*	-2.119	-3.015	-3.015	-1.850	-3.260	-2.249	-1.399	-1.893	-2.077	-1.714
HCO_3^- (Calculated)*	144.8	24.2	180.4	29.24	141.7	91.92	64.85	41.03	93.16	62.99
Cl	23	22	21	15	21	24	31	52	1200	21
F	0.26	< 0.10	0.85	< 0.10	0.48	< 0.10	< 0.10	< 0.10	3.88	< 0.10
I	---	---	---	---	---	---	---	---	< 1	---
Br	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	2.4	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	---	---	---	---	---	---	---	0.07
Nitrate+Nitrite (N)	---	---	---	---	---	---	---	---	---	0.07
Nitrite Nitrogen (N)	---	---	---	---	---	---	---	---	---	< 0.005
SO_4	6.4	3.9	4.5	3.2	4.9	4.4	7.1	3.3	< 1.0	2.7
Al	< 0.02	0.03	< 0.02	< 0.02	< 0.02	< 0.02	0.02	0.05	< 0.02	0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.007	0.006	0.065	0.007	0.057	0.044	0.024	0.005	0.186	0.009
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.244	0.018	0.598	0.015	0.272	0.084	0.054	0.015	4.14	0.018
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	1.88	6.65	19.8	5.79	17.3	24.5	17.2	13.3	36.7	20.9
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	0.098	< 0.005	0.049	< 0.005	< 0.005	0.007	< 0.005	0.01	0.012
Fe	0.012	0.012	< 0.005	0.033	< 0.005	< 0.005	0.062	0.426	0.108	0.19
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	0.54	2.96	4.26	2.3	6.02	4.21	5.55	6.14	1.79	3.44
Mn	< 0.001	0.001	0.038	0.007	0.009	0.082	0.006	0.14	0.043	0.038
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.2	< 0.1
K	< 1	< 1	1	< 1	2	1	< 1	< 1	2	< 1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	75.4	12.7	56.1	11.8	45	22.6	24	27.7	755	15.4
Sr	0.047	0.041	0.433	0.038	0.414	0.243	0.091	0.08	1.69	0.091

S	4.4	2.8	3.1	2.3	3.9	2.9	4.3	2.6	0.1	1.9
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	0.009	0.034	< 0.005	0.016	< 0.005	0.008	0.04	0.006	0.053	0.052
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	WB-5	WB-6	WB-7	WB-8	WB-9	WB-10	WB-11	WB-12	WB-13	WB-14
Depth (m) or Location	5	72	15	50	55	97	18	34	46	68
pH (Lab)	8.1	7.8	6.8	8.4	8.6	8.1	6.8	9	7.2	8.9
pH (Field)	7.2	7.1	6.2	8.1	8.7	8.2	6.6	8.9	6.9	8.6
T Alk HCO_3 (Field)	166	228	43	260	139	121	46	283	87	251
Cond.	343	413	128	374	10450	2400	213	450	168	405
T Hard. (Lab)	134	82.3	44.2	7	14.9	59.1	30.4	4.2	53.4	6.3
Temp. (Field)	13.9	10.7	12.7	13.8	13.3	12.6	12.6	12.2	13.7	13.6
Log pCO_2 (Calculated)*	-2.109	-1.867	-2.812	-4.634	-4.634	-3.299	-2.045	-3.605	-3.340	-3.340
HCO_3 (Calculated)*	163.7	225.7	43.14	255.5	125.9	115	44.88	261.5	86.11	240.6
Cl	53	56	25	26	380	680	45	37	25	46
F	0.17	0.7	< 0.10	1.5	3.9	4.13	0.12	0.47	0.6	0.91
I	< 1	---	---	---	---	< 1	---	---	---	---
Br	< 1.0	< 1.0	< 1.0	< 1.0	1.5	3.6	< 1.0	< 1.0	< 1.0	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	---	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	---	---	---	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	---	---	---	---	---	---	---	---	---	---
SO_4	10.4	1.1	4.6	9.8	< 1.0	4.3	3.4	16.7	4.9	7.4
Al	< 0.02	0.03	< 0.02	< 0.02	< 0.02	< 0.02	0.13	< 0.02	< 0.02	< 0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.065	0.008	0.005	0.007	0.015	0.039	0.008	0.003	0.011	0.003
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.181	0.775	0.015	1.54	4.51	4.91	0.272	0.713	0.516	1.21
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	36.2	26	11.4	2.44	5.59	19.7	6.33	1.57	14.4	2.38
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	< 0.005	0.01	< 0.005	< 0.005	< 0.005	0.053	< 0.005	< 0.005	< 0.005
Fe	0.45	1.17	0.167	0.012	0.02	0.052	0.095	0.012	0.008	0.008
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	10.5	4.21	3.83	0.21	0.22	2.4	3.54	0.07	4.23	0.08
Mn	0.119	0.095	0.014	0.005	0.003	0.028	0.01	0.001	0.001	0.001
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	< 0.1	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.2	< 0.1	< 0.1
K	2	3	< 1	< 1	< 1	1	< 1	< 1	< 1	< 1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	49.5	92.7	17.1	120	285	476	36.2	143	27.1	130
Sr	0.646	0.142	0.059	0.087	0.266	0.897	0.1	0.068	0.13	0.067

S	5.9	1.2	3.3	8.5	2.5	4.2	2.4	8.3	3.4	4.6
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	0.007	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	0.019	0.01	0.006	< 0.005	< 0.005	< 0.005	0.049	< 0.005	0.006	< 0.005
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	WB-15	WB-16	WB-17	SV-1	SV-2	SV-3	SS-1	SS-2	SS-3	SS-4
Depth (m) or Location	46	Well	6	Spring	Surface	Surface	38	6	76	43
pH (Lab)	7.6	8.1	8.1	7.1	6.5	7.4	9.1	8.2	8.3	9
pH (Field)	7.3	7.5	7.5	6.6	7.1	7	9.3	7.7	8	9.1
T Alk HCO_3^- (Field)	187	198	253	45	10	40	457	184	174	256
Cond.	450	484	483	106.7	81.5	101	768	275	291	338
T Hard. (Lab)	82.8	70.5	164	49.9	28.8	38.3	2.3	69.2	< 1.1	< 0.8
Temp. (Field)	13.0	13.1	12.1	13.8	14.8	12.6	13.3	15.3	13.9	13.5
Log pCO_2 (Calculated)*	-2.160	-2.336	-2.237	-2.056	-3.257	-2.500	-3.855	-2.561	-2.881	-3.861
HCO_3^- (Calculated)*	184.6	195.4	248.1	44.95	7.366	40.06	372.7	149.2	172	227.5
Cl	50	98	76	14	14	16	79	13	14	13
F	0.56	1.3	0.21	< 0.10	< 0.10	< 0.10	1.68	0.21	< 0.10	0.34
I	< 1	---	---	---	---	---	---	---	---	---
Br	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Nitrate Nitrogen Dissolved (N)	---	0.13	< 0.02	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	---	0.13	< 0.02	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	---	0.005	0.006	---	---	---	---	---	---	---
SO_4	16.9	15.3	1.9	8.2	10.6	2.7	< 1.0	10.7	20.4	7.9
Al	< 0.02	< 0.02	< 0.02	< 0.02	0.29	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.064	0.061	0.124	0.008	0.013	0.012	0.027	0.106	0.005	0.004
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.695	1.33	0.206	0.016	< 0.008	0.011	1.08	0.149	0.925	0.285
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	27.6	19.8	45.9	14.9	8.27	10.5	0.75	20.9	0.35	0.23
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	0.016	< 0.005	0.009	0.008	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Fe	0.355	< 0.005	2.83	0.086	0.475	0.881	0.018	0.188	< 0.005	0.012
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	3.37	5.11	12	3.08	1.97	2.94	0.11	4.14	< 0.05	< 0.05
Mn	2.48	0.02	0.31	0.003	0.017	0.05	< 0.001	0.11	< 0.001	< 0.001
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.4	< 0.1	0.1	0.1
K	2	2	2	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	95.3	116	80.7	10.9	9.95	12.2	235	55.2	140	107
Sr	0.824	0.404	0.836	0.077	0.058	0.069	0.03	0.288	0.026	0.007

S	9.8	7.6	1.4	4.7	5.8	2	2.7	5.6	10.9	5.4
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	< 0.005	0.015	0.049	0.126	0.011	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	SS-5	SS-6	SS-7	C-1	C-2	R2D2	PP-1	PP-2	PP-3	PP-4
Depth (m) or Location	37	16	17	Control	Control	Rain Water	6	23	28	37
pH (Lab)	9.3	9.1	9.1	6	8.3	5.6	8	7.7	9.3	8.4
pH (Field)	9.3	9.2	9.1	6	8.2	5.8	7.6	7.3	9.3	8.3
T Alk HCO_3 (Field)	340	303	285	15	122	17	123	120	357	242
Cond.	484	624	389	3.4	34300	13	236	198	514	411
T Hard. (Lab)	1.7	3.8	< 0.9	< 0.4	4230	1.2	122	32.5	2.5	9.1
Temp. (Field)	12.3	12.9	13.8	14.9	14.8	18.6	11.7	12.2	21.1	13.3
Log pCO_2 (Calculated)*	-2.969	-3.917	-3.815	-1.840	-3.405	-1.567	-1.355	-2.338	-3.928	-3.047
HCO_3 (Calculated)*	281.6	260.2	251.9	14.64	87.74	17.01	121.3	118.9	292.4	235.1
Cl	23	96	20	< 1.0	16000	< 1.0	25	14	27	55
F	0.42	0.63	0.57	< 0.10	0.72 (2)	< 0.10	< 0.10	0.19	2.37	1.36
I	---	---	---	---	< 1	---	---	---	< 1	---
Br	< 1.0	< 1.0	< 1.0	< 1.0	63	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	---	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	---	---	---	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	---	---	---	---	---	---	---	---	---	---
SO_4	4.6	4.1	< 1.0	< 1.0	2320	1.1	20.5	5.3	7.6	3.3
Al	0.03	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.009	0.026	0.007	0.002	0.007	0.007	0.058	0.022	0.01	0.011
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.463	0.602	0.425	< 0.008	2.96	< 0.008	0.053	0.15	1.16	0.779
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	0.58	1.05	0.26	0.08	265	0.23	35.7	10.1	0.82	2.38
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.032	< 0.005	< 0.005
Fe	0.02	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.07	0.009	< 0.005	0.053
Pb	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	0.07	0.29	< 0.05	< 0.05	866	0.15	8.04	1.77	0.12	0.77
Mn	0.003	0.001	< 0.001	< 0.001	< 0.001	0.006	0.15	0.004	< 0.001	0.016
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.006	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	< 0.1	0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.3
K	< 1	< 1	< 1	< 1	300	< 1	1	< 1	< 1	< 1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	150	184	124	0.54	8940	0.57	17.1	47.6	161	132

Sr	0.016	0.043	0.009	0.005	4.71	0.006	0.559	0.119	0.039	0.052
S	3	13.4	0.7	< 0.1	767	0.5	9.3	3.7	6	2.5
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	1.05	0.083	< 0.016	< 0.005	< 0.005
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

	PP-5	PP-6	PP-7	PP-8	PP-10	PP-11	PP-12	PP-13	PP-14	PP-15
Depth (m) or Location	Dug (4 m)	53	Well	Well	38	9	Well	Dug (4 m)	Well	Well
pH (Lab)	7.3	7.4	8.9	8.5	8.6	8.3	8.2	7	8.6	8.4
pH (Field)	6.8	6.7	9.2	8.7	8.6	8	7.6	6.6	8	8.8
T Alk HCO_3 (Field)	48	88	362	251	287	220	151	16	199	532
Cond	106	194	1080	446	529	318	223	72	314	1568
T Hard. (Lab)	43.2	99.5	5	2.7	14.9	4.7	28.2	19.5	3.3	6.9
Temp. (Field)	12.5	18.7	12.9	14.2	15.3	16.0	13.8	13.0	14.1	14.4
Log pCO_2 (Calculated)*	-2.232	-1.872	-3.853	-3.446	-3.284	-2.767	-2.541	-2.502	-2.804	-2.255
HCO_3^- (Calculated)*	47.37	87.68	303.5	238.2	273	217.2	150	15.57	195.6	490.1
Cl	13	22	270	57	25	20	14	11	24	410
F	< 0.10	< 0.10	1.81	0.66	0.44	0.68	0.19	< 0.10	0.35	2.96
I	---	---	---	---	---	---	---	---	---	< 1
Br	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	1.6
Nitrate Nitrogen Dissolved (N)	---	---	---	---	---	---	---	---	---	---
Nitrate+Nitrite (N)	---	---	---	---	---	---	---	---	---	---
Nitrite Nitrogen (N)	---	---	---	---	---	---	---	---	---	---
SO_4	3.2	7.8	2.2	< 1.0	64	< 1.0	2.4	1.5	1.5	< 1.0
Al	< 0.02	< 0.02	0.03	< 0.02	< 0.02	< 0.02	< 0.02	0.05	0.03	< 0.02
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Ba	0.005	0.014	0.036	0.014	0.034	0.015	0.058	0.022	0.012	0.073
Be	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
B	0.01	0.014	1.36	0.493	0.442	0.44	0.157	0.009	0.291	1.85
Cd	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Ca	12.9	31.1	1.59	0.8	4.35	1.44	8.16	4.37	0.92	2.14
Cr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Cu	0.05	0.066	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Fe	< 0.005	< 0.005	0.009	0.008	0.005	< 0.005	0.049	0.034	0.01	< 0.005
Pb	< 0.03	0.07	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Mg	2.66	5.3	0.26	0.17	0.99	0.27	1.91	2.09	0.24	0.37
Mn	0.036	0.008	0.003	0.002	0.01	0.003	0.062	0.024	0.002	0.002
Mo	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	< 0.1	< 0.1	0.3	0.2	0.1	< 0.1	0.2	< 0.1	0.2	0.6
K	< 1	1	< 1	< 1	< 1	< 1	< 1	1	< 1	< 1
Se	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Ag	0.03	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Na	10.8	15	308	134	161	96.3	59.6	10.9	98	400
Sr	0.061	0.145	0.085	0.031	0.117	0.029	0.156	0.06	0.028	0.122

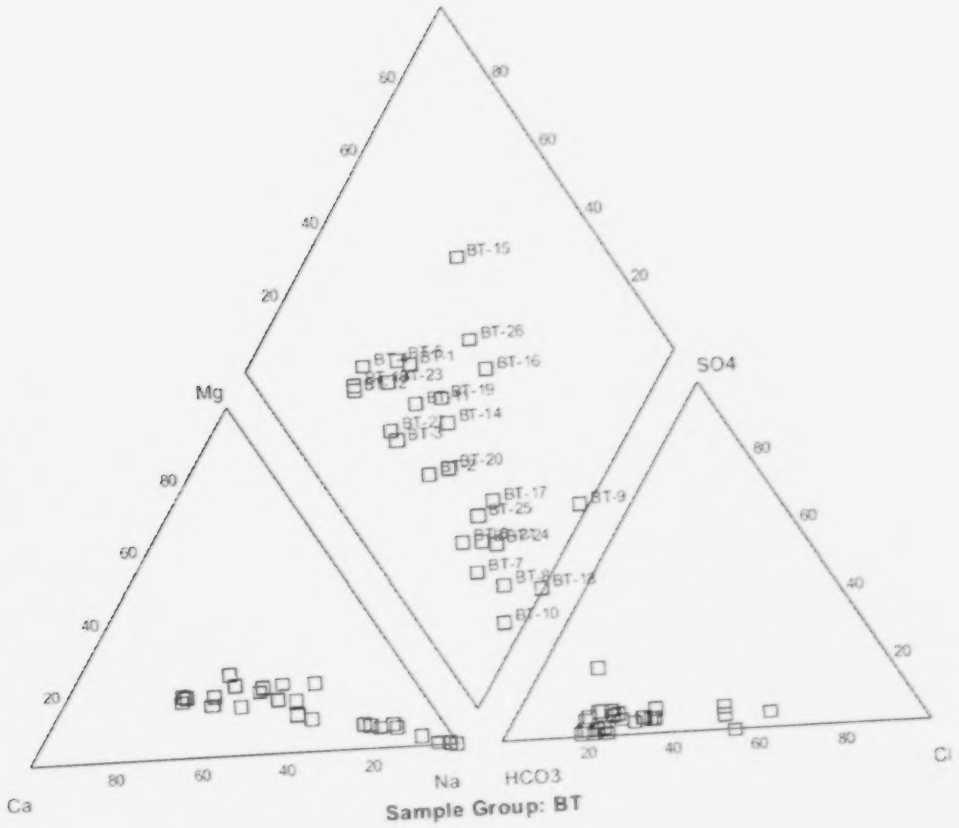
S	2.2	4.5	19.8	0.7	31.9	0.7	2	1.1	1.4	0.3
Te	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ti	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Zn	0.016	0.191	< 0.005	< 0.005	< 0.005	< 0.005	0.023	< 0.009	< 0.005	< 0.005
Zr	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

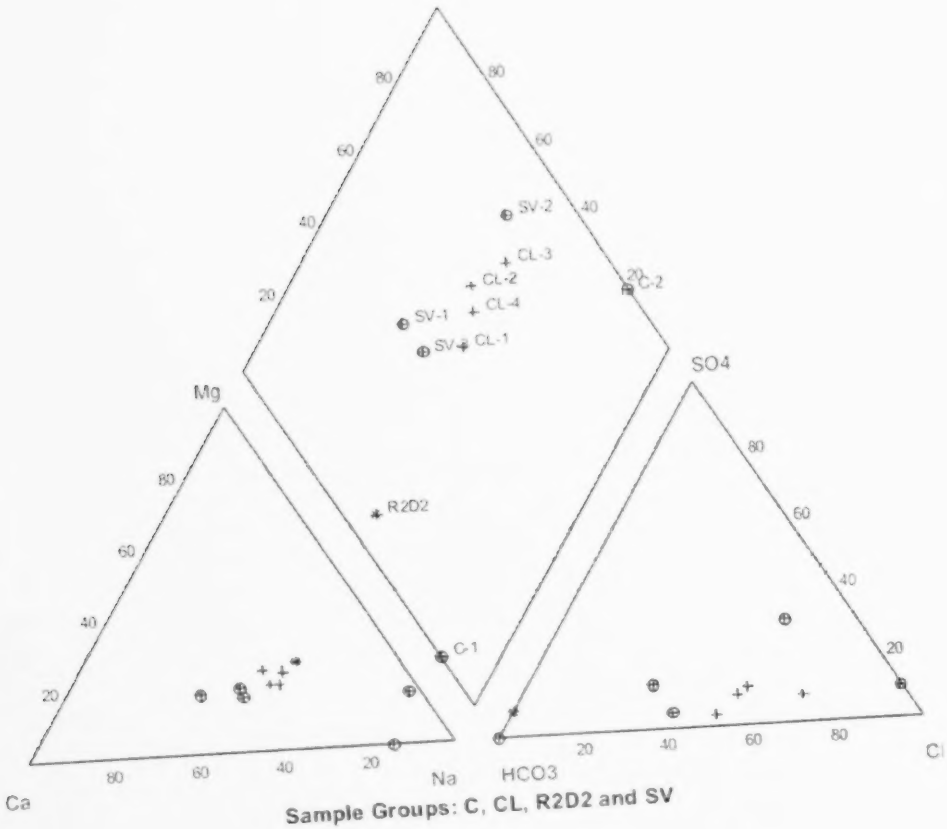
	PP-16	PP-17	PP-18
Depth (m) or Location	Well	43	20
pH (Lab)	8.4	7.8	7.6
pH (Field)	8.5	7.3	6.9
T Alk HCO_3 (Field)	248	104	57
Cond.	527	202	146
T Hard. (Lab)	4.5	24.7	59.7
Temp. (Field)	14.4	12.2	15.5
Log pCO_2 (Calculated)*	-3.251	-2.388	-2.257
HCO_3 (Calculated)*	238.8	103.1	57
Cl	100	17	17
F	0.61	0.16	< 0.10
I	---	---	---
Br	< 1.0	< 1.0	< 1.0
Nitrate Nitrogen Dissolved (N)	---	---	---
Nitrate+Nitrite (N)	---	---	---
Nitrite Nitrogen (N)	---	---	---
SO_4	< 1.0	11.6	9
Al	< 0.02	< 0.02	< 0.02
Sb	< 0.05	< 0.05	< 0.05
As	< 0.05	< 0.05	< 0.05
Ba	0.022	0.034	0.016
Be	< 0.0002	< 0.0002	< 0.0002
Bi	< 0.05	< 0.05	< 0.05
B	0.485	0.148	0.025
Cd	< 0.002	< 0.002	< 0.002
Ca	1.35	6.55	17.1
Cr	< 0.005	< 0.005	< 0.005
Co	< 0.005	< 0.005	< 0.005
Cu	< 0.005	0.007	0.007
Fe	0.022	0.009	< 0.005
Pb	< 0.03	< 0.03	< 0.03
Mg	0.27	2.02	4.14
Mn	0.009	0.006	< 0.001
Mo	< 0.005	< 0.005	< 0.005
Ni	< 0.008	< 0.008	< 0.008
P (as Orthophosphate)	0.3	< 0.1	< 0.1
K	< 1	< 1	< 1
Se	< 0.03	< 0.03	< 0.03
Ag	< 0.01	< 0.01	< 0.01
Na	158	46.9	14.1
Sr	0.043	0.094	0.177
S	4.4	6.3	5
Te	< 0.05	< 0.05	< 0.05
Tl	< 0.03	< 0.03	< 0.03
Sn	< 0.02	< 0.02	< 0.02

Ti	< 0.003	< 0.003	< 0.003
V	< 0.005	< 0.005	< 0.005
Zn	< 0.005	0.023	0.018
Zr	< 0.005	< 0.005	< 0.005

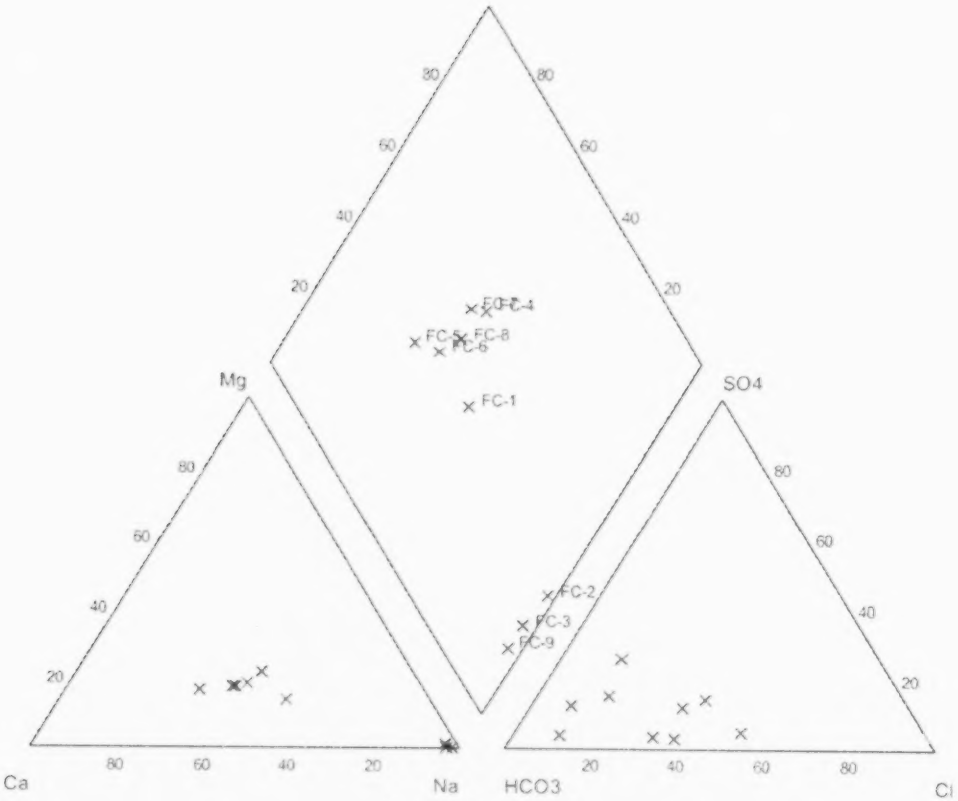
APPENDIX B

PIPER PLOTS FOR ALL SAMPLE GROUPS

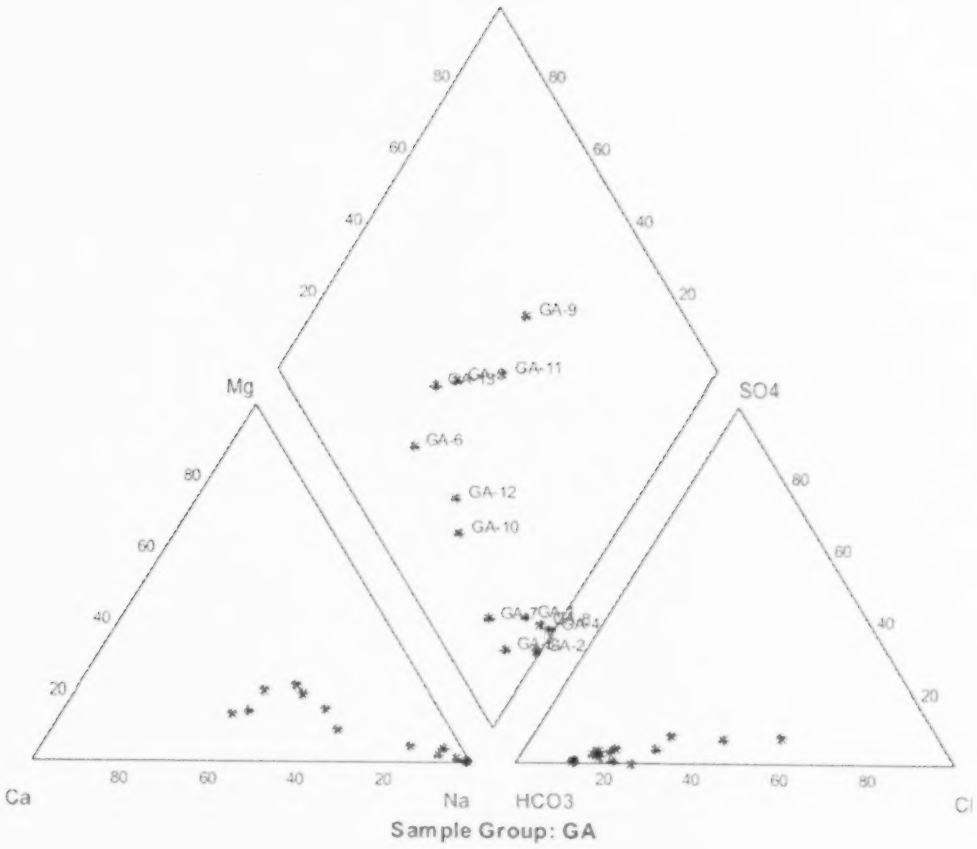

Mg
SO4
Ca
Na
HCO3
Cl
BT-15
BT-26
BT-16
BT-23
BT-19
BT-14
BT-20
BT-17
BT-25
BT-9
BT-7
BT-10
Sample Group: BT



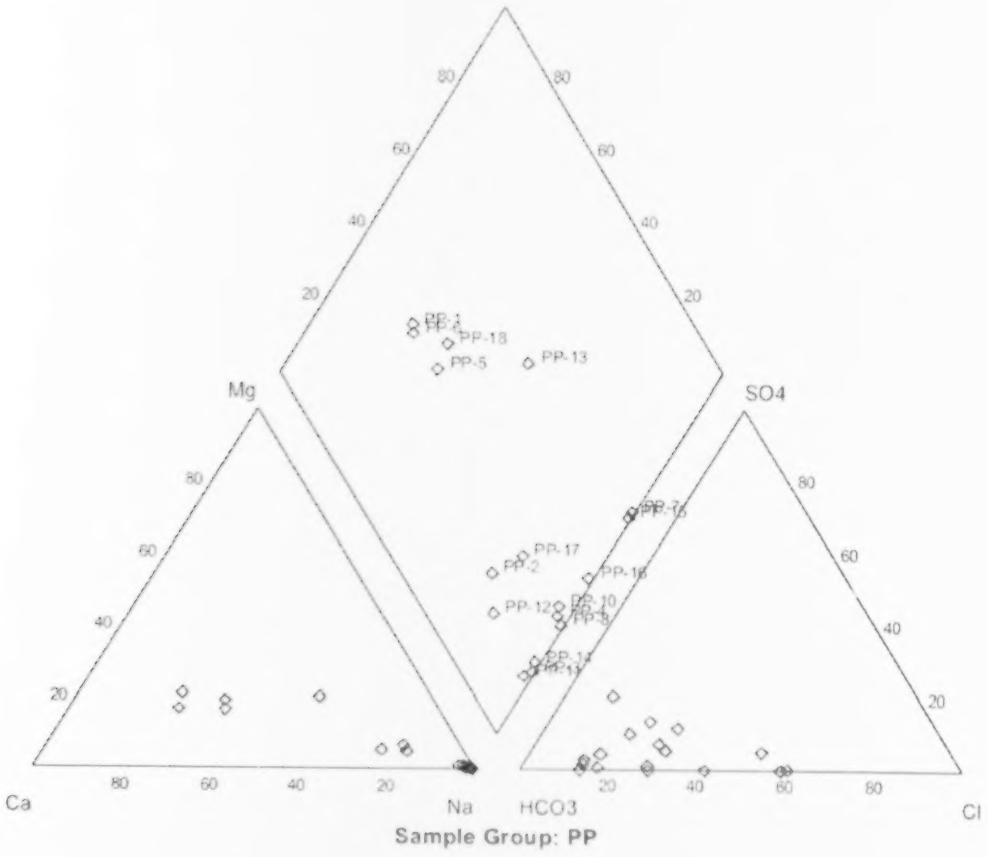
Sample Groups: C, CL, R2D2 and SV



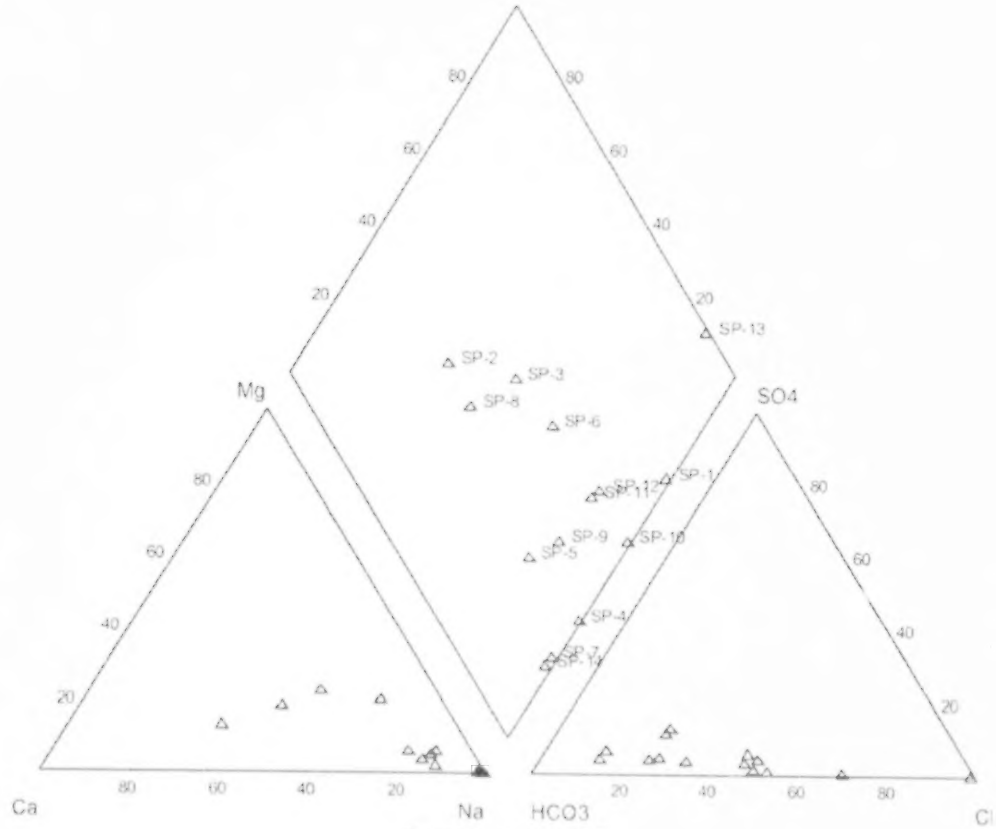
Sample Group: FC



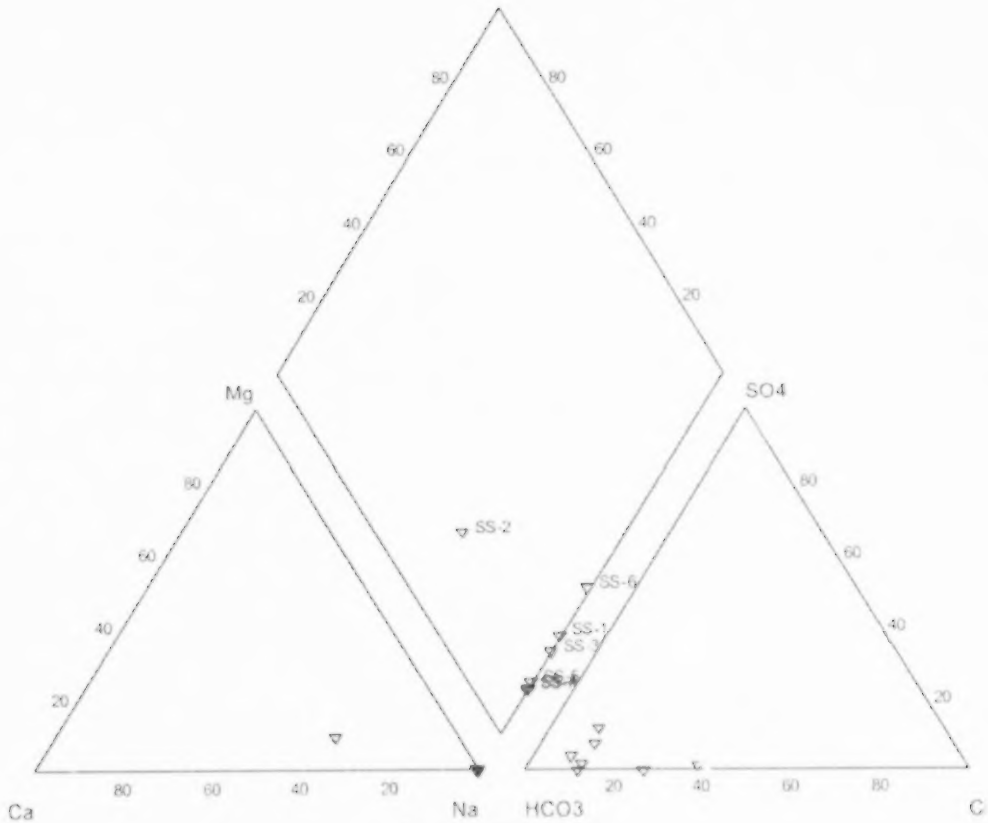
Sample Group: GA



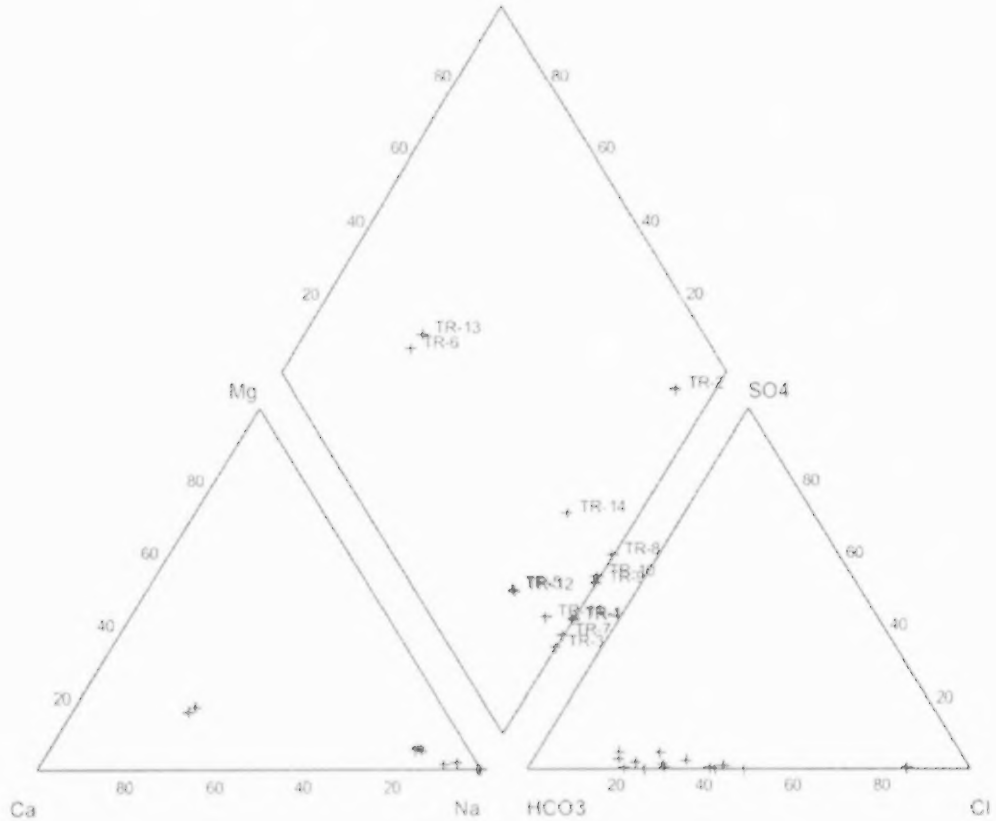
Sample Group: PP



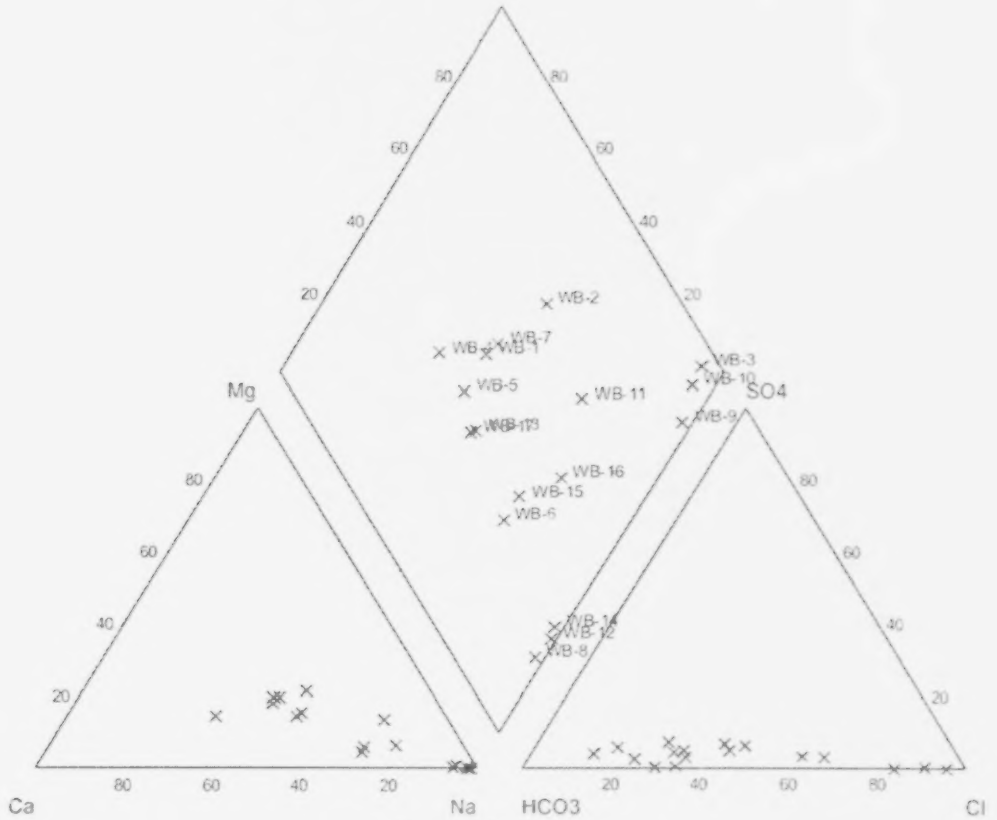
Sample Group: SP



Sample Group: SS



Sample Group: TR



Sample Group: WB

APPENDIX C

CONCENTRATION MAPS

Barium Concentrations (mg/L)

Boron Concentrations (mg/L)

Calcium Concentrations (mg/L)

Chloride Concentrations (mg/L)

Flouride Concentrations (mg/L)

Iron Concentrations (mg/L)

Manganese Concentrations (mg/L)

Sodium Concentrations (mg/L)

APPENDIX D

SAMPLE SOLMINEQ OUTPUT: SAMPLE BT-1

SAMPLE IDENT: BT-1

PH	EH	TEMP		CATIONS	ANIONS	DIFFERENCE (MEQ/L)	--- H - OH BALANCE (MOLES) -------		
7.20	9.0000	14.70	ANAL=	4.0561	1.9600	2.0962	HTOT	OHTOT	DIFFERENCE
			CALC=	4.0300	1.9354	2.0946	0.1475E-02	0.6048E-04	0.1415E-02

				PRESSURE					
DENSITY AT INPUT T	TOTAL DISSOLVED SOLIDS (MG/L)	IONIC STRENGTH	ACTIVITY OF WATER	P TOTAL (BARS)	PH2O (BARS)	PCO2 (BARS)	PH2S (BARS)	PCH4 (BARS)	PNH3 (BARS)
1.0001	181.65	0.00424	0.9999	1.0000	0.1672E-01	0.4018E-02	0.0000E+00	0.0000E+00	0.0000E+00

Dissolved Inorganic Carbon

	Total Alkalinity as			as	HCO3-	H2CO3	Sum of	Sum of
	HCO3-	CO3=	CaCO3	TIC	Alkalinity	species	HCO3-	CO3=
(MG/L)=	0.6910E+02	0.3398E+02	0.5667E+02		0.1566E+02	0.6908E+02	0.1073E+02	0.6890E+02	0.9038E-01
(PPM)=	0.6909E+02	0.3397E+02	0.5666E+02		0.1566E+02	0.6907E+02	0.1073E+02	0.6889E+02	0.9037E-01
(MOLALITY)=	0.1133E-02	0.5663E-03	0.5663E-03		0.1304E-02	0.1132E-02	0.1730E-03	0.1129E-02	0.1506E-05

	ANALYZED			CALCULATED			ACTIVITY	-LOG10
SPECIES	PPM	MG/L	MOLALITY	PPM	MG/L	MOLALITY	ACTIVITY	COEFF.	ACTIVITY
1 Ca ++	32.9959	33.0000	0.8234E-03	0.3254E+02	0.3254E+02	0.8120E-03	0.6218E-03	0.7657	3.2064
2 Mg ++	9.8388	9.8400	0.4048E-03	0.9687E+01	0.9689E+01	3985E-03	0.3082E-03	0.7732	3.5112
3 Na +	35.1956	35.2000	0.1531E-02	0.3516E+02	0.3516E+0	0.1530E-02	0.1428E-02	0.9333	2.8454
4 K +	1.9998	2.0000	0.5115E-04	0.1999E+01	0.1999E+01	0.5114E-04	0.4766E-04	0.9320	4.3219
5 Cl -	25.9968	26.0000	0.7334E-03	0.2599E+02	0.2599E+02	0.7332E-03	0.6833E-03	0.9320	3.1654
6 SO4 --	4.5994	4.6000	0.4789E-04	0.3956E+01	0.3957E+01	0.4119E-04	0.3121E-04	0.7578	4.5057
7 HCO3 -	68.9914	69.0000	0.1131E-02	0.6817E+02	0.6818E+02	0.1117E-02	0.1044E-02	0.9339	2.9815
8 H +			0.6776E-04	0.6776E-04	0.6723E-07	0.6313E-07	0.9391	7.1997	
9 OH -			0.1284E-02	0.1284E-02	0.7552E-07	0.7044E-07	0.9326	7.1522	
15 Ba ++	0.0660	0.0660	0.4806E-06	0.6446E-01	0.6447E-01	0.4694E-06	0.3576E-06	0.7618	6.4466
16 Cu +	0.0220	0.0220	0.3463E-06	0.1588E-01	0.1588E-01	0.2500E-06	0.2328E-06	0.9313	6.6330
23 Mn ++	0.0390	0.0390	0.7099E-06	0.3826E-01	0.3827E-01	0.6966E-06	0.5334E-06	0.7657	6.2729
26 Sr ++	0.6139	0.6140	0.7008E-05	0.6060E+00	0.6061E+00	0.6918E-05	0.5270E-05	0.7618	5.2782
27 Zn ++	0.0310	0.0310	0.4743E-06	0.3005E-01	0.3005E-01	0.4597E-06	0.3520E-06	0.7657	6.4534

31	B(OH)3	1.2411	1.2412	0.2008E-04	0.1231E+01	0.1231E+01	0.1991E-04	0.1993E-04	1.0007	4.7006
51	BaCO3			0.1230E-04	0.1230E-04	0.6233E-10	0.6237E-10		1.0007	10.2050
52	BaHCO3 +			0.1716E-02	0.1716E-02	0.8652E-08	0.8075E-08		0.9333	8.0929
53	BaOH +			0.1281E-07	0.1282E-07	0.8304E-13	0.7760E-13		0.9345	13.1101
54	BaSO4			0.5678E-03	0.5679E-03	0.2433E-08	0.2435E-08		1.0007	8.6135
55	CaCO3			0.5363E-01	0.5364E-01	0.5360E-06	0.5364E-06		1.0007	6.2705
56	CaHCO3 +			0.7223E+00	0.7224E+00	0.7146E-05	0.6687E-05		0.9357	5.1748
57	CaOH +			0.3303E-04	0.3304E-04	0.5787E-09	0.5415E-09		0.9357	9.2664
61	CaSO4			0.5088E+00	0.5089E+00	0.3738E-05	0.3741E-05		1.0007	5.4270
62	CuCl			0.8493E-02	0.8494E-02	0.8581E-07	0.8587E-07		1.0007	7.0661
63	CuCl2 -			0.1408E-02	0.1408E-02	0.1047E-07	0.9776E-08		0.9333	8.0098
64	CuCl3 --			0.2276E-05	0.2276E-05	0.1340E-10	0.1021E-10		0.7618	10.9911
89	B(OH)4 -			0.1290E-01	0.1290E-01	0.1636E-06	0.1524E-06		0.9314	6.8171
97	H2CO3			0.1073E+02	0.1073E+02	0.1730E-03	0.1731E-03		1.0007	3.7616
98	CO3 --			0.4789E-01	0.4789E-01	0.7981E-06	0.6064E-06		0.7598	6.2172
103	HSO4 -			0.1338E-04	0.1338E-04	0.1379E-09	0.1287E-09		0.9339	9.8903
113	KCl			0.2861E-03	0.2862E-03	0.3839E-08	0.3842E-08		1.0007	8.4155
114	KCO3 -			0.3462E-04	0.3462E-04	0.3493E-09	0.3259E-09		0.9330	9.4869
115	KHSO4			0.4825E-08	0.4825E-08	0.3544E-13	0.3546E-13		1.0007	13.4502
116	KSO4 -			0.1617E-02	0.1617E-02	0.1197E-07	0.1119E-07		0.9350	7.9512
120	MgCO3			0.1349E-01	0.1349E-01	0.1600E-06	0.1601E-06		1.0007	6.7956
121	MgHCO3 +			0.3241E+00	0.3241E+00	0.3798E-05	0.3545E-05		0.9333	5.4504
123	MgOH +			0.3580E-03	0.3581E-03	0.8667E-08	0.8115E-08		0.9363	8.0907
124	MgSO4			0.2718E+00	0.2719E+00	0.2259E-05	0.2260E-05		1.0007	5.6458
128	MnCl +			0.1094E-10	0.1094E-10	0.1210E-15	0.1129E-15		0.9333	15.9472
129	MnCl2			0.2309E-10	0.2309E-10	0.1835E-15	0.1836E-15		1.0007	15.7361
130	MnCl3 -			0.5336E-12	0.5337E-12	0.3309E-17	0.3088E-17		0.9333	17.5103
131	MnCl4 --			0.3832E-14	0.3832E-14	0.1948E-19	0.1484E-19		0.7618	19.8286
132	MnHCO3 +			0.1236E-02	0.1236E-02	0.1066E-07	0.9949E-08		0.9333	8.0022
133	MnSO4			0.3823E-03	0.3823E-03	0.2532E-08	0.2534E-08		1.0007	8.5962
135	MnOH +			0.7655E-05	0.7656E-05	0.1064E-09	0.9932E-10		0.9333	10.0030
137	NaCl			0.7318E-02	0.7319E-02	0.1252E-06	0.1253E-06		1.0007	6.9019
138	NaCO3 -			0.8480E-03	0.8481E-03	0.1022E-07	0.9555E-08		0.9350	8.0198
139	NaHCO3			0.6182E-01	0.6183E-01	0.7361E-06	0.7366E-06		1.0007	6.1328
140	Na2CO3			0.2030E-07	0.2031E-07	0.1916E-12	0.1917E-12		1.0007	12.7173
142	NaSO4 -			0.7850E-01	0.7851E-01	0.6595E-06	0.6166E-06		0.9350	6.2100
154	SrOH +			0.1806E-06	0.1806E-06	0.1727E-11	0.1613E-11		0.9345	11.7922
155	SrCO3			0.2287E-03	0.2287E-03	0.1549E-08	0.1550E-08		1.0007	8.8096
156	SrHCO3 +			0.9549E-02	0.9550E-02	0.6426E-07	0.5997E-07		0.9333	7.2221
157	SrSO4			0.4428E-02	0.4429E-02	0.2411E-07	0.2413E-07		1.0007	7.6175
158	ZnCl +			0.4352E-04	0.4352E-04	0.4317E-09	0.4029E-09		0.9333	9.3948
159	ZnCl2			0.6023E-07	0.6024E-07	0.4421E-12	0.4424E-12		1.0007	12.3542
160	ZnCl3 -			0.3579E-10	0.3579E-10	0.2084E-15	0.1945E-15		0.9333	15.7110
161	ZnCl4 --			0.1100E-13	0.1100E-13	0.5311E-19	0.4046E-19		0.7618	19.3930
162	ZnSO4			0.2561E-03	0.2561E-03	0.1587E-08	0.1588E-08		1.0007	8.7992
282	CaCl2			0.4546E-05	0.4546E-05	0.4097E-10	0.4100E-10		1.0007	10.3873

292 ZnHCO3 +	0.1194E-02	0.1195E-02	0.9453E-08	0.8822E-08	0.9333	8.0544
293 ZnOH +	0.2525E-03	0.2525E-03	0.3065E-08	0.2861E-08	0.9333	8.5435
294 Zn(OH)2	0.1432E-05	0.1433E-05	0.1442E-10	0.1443E-10	1.0007	10.8408

MOLE RATIOS (USING ANALYTICAL MOLALITY)

CL/CA	CL/MG	CL/NA	CL/K	CL/AL	CL/FE	CL/SO4	CL/HCO3	CA/MG	SQRT(CA)/NA
0.8907E+00	0.1812E+01	0.4790E+00	0.1434E+02	0.0000E+00	0.0000E+00	0.1531E+02	0.6485E+00	0.2034E+01	0.1874E+02

NH3/NA	LI/NA	K/NA	MG/CA	SR/CA	BA/CA	SO4/CL	HCO3/CL	F/CL	B/CL
0.0000E+00	0.0000E+00	0.3341E-01	0.4916E+00	0.8511E-02	0.5837E-03	0.6530E-01	0.1542E+01	0.0000E+00	0.2737E-01

LOG OF ACTIVITY RATIOS

CA/H2	MG/H2	NA/H	K/H	AL/H3	FE/H2	CA/MG	NA/K
0.1119E+02	0.1089E+02	0.4354E+01	0.2878E+01	0.0000E+00	0.0000E+00	0.3049E+00	0.1476E+01

LOG(NA/K)+1/3(LOG(SQRT(CA)/NA)) = 0.190E+01
LOG(NA/K)+4/3(LOG(SQRT(CA)/NA)) = 0.776E+01

	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	DELG		PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	DELG
11	ANHYDRIT	-7.712	-4.219	-3.494	-4.601	83	NATRON	-11.908	-1.292	-10.616	-13.983
17	ARAGONIT	-9.424	-8.280	-1.143	-1.506	85	NESQUHON	-9.729	-5.068	-4.660	-6.138
20	BARITE	-10.952	-10.144	-0.809	-1.065	95	PERICLAS	10.888	22.458	-11.569	-15.238
22	BRUCITE	-17.816	-11.479	-6.337	-8.346	99	PORTLAN	-17.511	-5.331	-12.180	-16.042
24	CALCITE	-9.424	-8.430	-0.994	-1.309	100	POTASSI	5.756	86.799	-81.044	-106.743
25	CELESTIT	-9.784	-6.435	-3.348	-4.410	118	Na2O	8.709	69.638	-60.929	-80.250
41	DOLOMITE	-19.152	-17.888	-1.264	-1.664	122	SrCO3	-11.495	-9.275	-2.220	-2.924
42	DSORD	-19.152	-16.272	-2.880	-3.793	123	SYLVITE	-7.487	0.796	-8.283	-10.910
51	GYPSUM	-7.712	-4.597	-3.115	-4.103	125	THENARDI	-10.196	-0.289	-9.907	-13.049
52	HALITE	-6.011	1.562	-7.573	-9.974	127	TRONA	-17.735	-0.453	-17.282	-22.762

55	HUNTITE	-38.609	-29.878	-8.731	-11.499	130	WITHERIT	-12.664	-8.687	-3.977	-5.237
56	HYDRMAGN	-50.512	-37.775	-12.737	-16.776	139	Cu2O	1.133	-2.077	3.210	4.228
57	HYPHILIT	-9.537	12.299	-21.836	-28.760	163	MnCl2	-12.604	9.236	-21.840	-28.765
67	LIME	-17.606	33.874	-51.480	-67.804	164	MnCO3	-12.490	-10.511	-1.979	-2.606
70	MAGNESIT	-9.728	-7.857	-1.872	-2.466	165	MnO	8.127	18.452	-10.326	-13.600
71	MgCl2	-9.842	23.113	-32.955	-43.405	174	ZnCO3	-12.671	-9.545	-3.125	-4.117
76	MIRABILT	-10.197	-1.585	-8.612	-11.343	175	ZnO	7.946	11.870	-3.924	-5.169
81	NACHOLIT	-5.827	-0.544	-5.283	-6.958	177	ZnSO4	-10.959	4.025	-14.984	-19.735
82	NATRTHRM	-11.908	0.043	-11.951	-15.740						